SOUTHWEST FISHERIES SCIENCE CENTER

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DOLPHIN-SAFE RESEARCH PROGRAM PROGRESS REPORT II (1992-1996)

By

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ABSTRACT

NMFS research projects conducted during 1992-1996 were selected based on their potential to improve understanding of the behavioral association between yellowfin tuna and dolphins and on their potential to develop new methods of locating and aggregating sexually mature yellowfin tuna not associated with dolphins. Beginning in 1992, NMFS funded four specific research projects: 1) investigation of the feasibility of locating yellowfin tuna not visually associated with dolphins or other surface cues using airborne lidar, 2) evaluation of the potential for using environmental predictors of yellowfin tuna abundance, catchability and distribution, 3) two 30-day charters of a tuna purse-seine vessel to conduct simultaneous tagging and tracking of yellowfin tuna and dolphins, and 4) analysis of food-habits of dolphins, tunas, and other upper trophic-level predators in the ETP.

NMFS conducted a Second Research Planning Workshop during 1994, and supported cooperative FAD (Fish Aggregating Devices) research between NMFS and tuna vessel skippers in 1993-1994. During 1995, NMFS funded studies on the potential for low frequency, longer range acoustic systems, and enhancements to existing radar systems, to detect yellowfin tuna schools in the ETP. NMFS also conducted a workshop on methods to separate or attract tuna and dolphins, completed a report on recent use of FADs, estimated tuna bycatch in the ETP, and reviewed the dolphin-fishery interactions outside the ETP.

The Dolphin-Safe Research Program has completed two of three successive research cycles, and is currently nearing completion of the third cycle. The first cycle answered affirmatively the initial question of whether large yellowfin tuna are ever unassociated with dolphins in the ETP, and therefore might be available in commercially adequate numbers. The second cycle determined first, that locating such fish should be possible given the physical oceanographic environment of the ETP, and second, that the most appropriate medium to long range detection devices would be acoustic. Local detection could be improved over current methods by using newly developed and developing optical detection technologies (i.e., lidar and enhanced video). During the third (and last) research cycle, the Dolphin-Safe Research Program will determine the specifications for the optimal acoustic system for locating large unassociated yellowfin tuna in the ETP, and initiate planning for research surveys to determine distribution, abundance, and commercial potential of the resource.

If pending legislation becomes law, Program focus will revert to emphasis on dolphin management and protection.

Introduction

The expansion of the eastern tropical Pacific (ETP) tuna purse-seine fleet from the 1960's to the present has involved a long history of dolphin mortality incidental to fishing operations (NRC 1992, Joseph 1994). These dolphin deaths led to an escalating interaction between fishing interests, government, and environmental organizations. Amendments to the Marine Mammal Protection Act of 1972 (Section 110(a) November 23, 1988) directed the National Marine Fisheries Service (NMFS) to investigate methods to locate and capture large yellowfin tuna, *Thunnus albacares,* that do not involve encircling dolphins with a net. Successful introduction of such methods would help reduce, if not eliminate, the incidental mortality of dolphins which occurs in the ETP tuna purse-seine fishery (Perrin 1969), while maintaining a viable fishery resource. Congress further directed the Secretary of Commerce to arrange for an independent review of potential alternative fishing methods to be conducted by the National Research Council (NRC 1992). In response, the NMFS formed the Alternative Gear Task at the Southwest Fisheries Science Center (SWFSC) in La Jolla, California during the second half of 1989, and the Dolphin-Safe Research Program in 1992. This report summarizes Dolphin-Safe research activities during 1992-1996.

Research Progress

Overview

The Dolphin-Safe Research Program was initiated in 1992, the first year that significantly increased funding was allocated by Congress to NMFS specifically to address the tuna-dolphin issue following the major U.S. tuna cannery=s decision in April 1990, to buy only "dolphin-safe" tuna. During 1992, NMFS convened a research planning workshop to evaluate and prioritize proposed tuna-dolphin research. Following that workshop, NMFS developed a strategic plan (DeMaster 1992), published a report on research efforts through July 1991 (Young and Armstrong 1992), and initiated research on the top priorities identified by the research planning workshop.

These initial projects were selected based on their potential to 1) improve understanding of the behavioral association between yellowfin tuna and dolphins and 2) develop new methods of locating and aggregating sexually mature yellowfin tuna not associated with dolphins. In late 1992 (FY93), the NMFS Dolphin-Safe Research Program funded the four top priority research projects recommended by the planning workshop: 1) investigation of the feasibility of locating yellowfin tuna not visually associated with dolphins or other surface cues using airborne lidar, 2) evaluation of the potential for using environmental predictors of yellowfin tuna abundance, catchability and distribution, 3) two 30-day charters of a tuna purse-seine vessel to conduct simultaneous tagging and tracking of yellowfin tuna and dolphins, and 4) analysis of food-habits of dolphins, tunas, and other upper-trophic-level predators in the ETP. NMFS supported cooperative FAD research between NMFS and tuna vessel skippers in 1993-1994. Several projects initiated by NMFS and

IATTC in 1992 continued into 1993 (simultaneous tracking of dolphins and tuna and dolphins), 1994 (environmental predictors of yellowfin tuna abundance, catchability, and distribution), and 1995 (food habits of tuna, dolphins, and upper trophic level predators).

Having completed the major initiatives identified in the 1st research planning workshop (DeMaster 1992, Young and Armstrong 1992), NMFS in early 1994 held a second research planning workshop at the SWFSC to prioritize future research plans and projects (Edwards, Oliver, and Sisson 1995). Workshop discussions of alternatives were specifically focused on 1) large yellowfin tuna, 2) the eastern tropical Pacific Ocean area, 3) detection methods that exclude dolphin cues, and 4) capture methods that do not involve the encirclement of dolphins. The purpose of this focus was to identify promising new methods for detection of the larger yellowfin tuna commonly associated with dolphins in the ETP.

During 1995, NMFS' Dolphin-Safe Research Program completed a report on recent use of FADs (fish aggregating devices) in the fishery (Armstrong and Oliver 1996), conducted a one-day workshop in September 1995 to discuss and evaluate potential methods to attract and aggregate tuna or to separate tuna and dolphins prior to capture (Edwards, in prep), and funded the most highly recommended studies identified by the participants at the second planning workshop. These studies, completed during 1996, include 1) modeling of the acoustic target strengths of large yellowfin tuna schools (Nero 1996), 2) modeling the propagation of low frequency acoustic signals to detect yellowfin tuna schools (Rees 1996), and 3) an analysis of potential enhancements to existing radars for detecting large yellowfin tuna schools (Summers 1996).

The following sections describe these Dolphin-Safe Research Program projects in greater detail, summarize the important results obtained to date, and identify a larger body of published reports generated by the research efforts.

IATTC/NMFS Tracking Cruises

The primary objective of this two-year project was to study the relationship between yellowfin tuna, *Thunnus albacares*, and spotted dolphins, *Stenella attenuata*, by capturing, tagging, and simultaneously tracking both dolphins and tuna. Tuna and dolphin tags were equipped with pressure sensing devices which transmitted (tuna) or stored (dolphin) depth data, allowing subsequent analysis of vertical distribution for each species over time. These data have two important uses: 1) in conjunction with food-habits information, these data may help in understanding the degree to which the dolphin-tuna association is food-based, and 2) in determining whether the dolphin-tuna association weakens at particular times leaving the tuna more vulnerable to dolphin-safe fishing methods.

<u>Cruise I (1992)</u>. During 1992, NMFS contracted the U.S.-registered tuna purse-seine vessel *NICOLE K* to conduct 30 days of fishing operations in support of Dolphin-Safe research (PO 50ABNA300010; $593,782), to be conducted in cooperation with IATTC researchers Drs.

Michael Scott and Robert Olson under another contract obligation (PO 40ABNF202036; $133,000). Scientists from Mexico's Programa Nacional para el Aprovechamiento del Atún y Protección de los Delfines (PNAAPD) and the University of Hawaii also participated in this research cruise. From November 4, 1992 through December 7, 1992, the vessel *NICOLE K* participated in this research effort in conjunction with the NOAA research ship *McArthur*. NMFS obtained scientific research permits from Colombia, Costa Rica, El Salvador, France (Clipperton Island), Guatemala, Honduras, Nicaragua, Panama, and the United States. The scientific research was performed in the territorial waters of Costa Rica, Guatemala, Panama, and extended well into the international waters of the ETP (Figure 1).

The two main objectives during the first cruise were to develop and test techniques to capture, tag, and simultaneously track northern offshore spotted dolphins and yellowfin tuna in order to define the duration and dynamics of the tuna/dolphin association, and to conduct food-habits studies on tuna to determine the degree to which the association is food-based. A third objective was to determine whether the association breaks or loosens at particular times or during particular conditions to determine whether tuna would be vulnerable to fishing at such times.

Ancillary projects were planned and conducted by scientists aboard both the *NICOLE K* and the *McArthur* on an opportunistic basis to investigate further the mechanisms and nature of the tuna/dolphin association and gather information on other marine species including sea turtles, sharks, billfish, flying fish, and birds. Observations made on seabird flock activity relative to any schools of tuna observed could be used to develop a general hypothesis on tuna foraging. These observations were directed at determining whether seabird flock size and species composition are correlated to the actual size of the tuna school. Also of interest was how and when seabird flocks form and feed over schools of yellowfin tuna.

The *NICOLE K's* primary function was to facilitate tracking of dolphins and tuna by locating, capturing, tagging, and releasing spotted dolphins and yellowfin tuna prior to subsequent tracking by the *McArthur* and its launches. After an aggregation of tuna and dolphin had been encircled inside the purse-seine net, the *McArthur* deployed an 18-foot launch (AR-1) which was used as a platform to fish for yellowfin tuna inside the net with handline gear. Handline fishing proved to be ineffective, and a tuna fisherman, using snorkel, mask and flippers, attached ultrasonic- transmitter tags with a lance to free-swimming tuna before the backdown procedure. During pursing and net roll procedures, the *McArthur's* 27-foot auxiliary launches (AR-3 and AR-4) were deployed and directed to a position along the corkline to deploy the tagging team's rafts and personnel, and to be in position to conduct tracking operations following backdown. Both tracking launches were equipped with sonic and radio-tracking gear capable of tracking dolphins with attached radio-transmitters and tuna with attached ultrasonic transmitters as soon as the animals were released from the net. When approximately one-half of the net had been rolled aboard, three scientists from the *NICOLE K* and two tuna fishermen entered the water with masks, snorkels, and fins.

Dolphins were captured by these swimmers before backdown, delivered to the tagging team, and placed inside an inflatable raft. Each dolphin was outfitted with a radio-transmitter mounted on a plastic saddle which was attached to the dolphin's dorsal fin using two 1/4-inch Delrin pins. Tissue plugs, removed to attach the package, were saved for genetic analysis. The delrin pins were secured by magnesium nuts that corrode in seawater, releasing the package within several days to a few weeks. The color pattern, respiration rate, length, and sex of the tagged dolphins were recorded. Tagged dolphins were released inside the net so the entire aggregation of tuna and dolphins could be released from the purse-seine net together. Time-depth recorders (TDRs) that measured and stored depth information at 10-second intervals were also attached to the radio-transmitter packages of three tagged dolphins during the cruise. After tagging procedures were completed, the fishing master released the entire tuna/dolphin aggregation by either releasing the bow ortza or performing a modified backdown procedure.

Tuna tagging procedures were unprecedented and had to be developed during the cruise. Initial attempts at capturing tuna with baited hooks while fishing with handlines were unsuccessful. Ultimately, the telemetry package was attached to a pole spear, and used by swimmers or persons in speedboats stationed at the apex of the backdown channel to "lance-tag" free-swimming tuna. Lance-tagging proved very effective and remains the method of choice. Tags were attached to the dorsal musculature of the tuna.

Results. Of the thirteen sets were made during the 30-day charter period, eleven sets involved northern offshore spotted dolphin schools (Figure 1). Seven northern offshore spotted dolphins were captured by swimmers inside the net during six sets, and six dolphins from five of these sets (4, 7-10) were equipped with telemetry packages attached to the dorsal fins of the dolphins (IATTC 1993, Armstrong 1993). Radio-transmitters were attached to the dorsal fins of all six dolphins, and TDRs were attached to the radio-transmitter packages of three dolphins. Two of the TDR packages were subsequently recovered during sets on previously tagged dolphins. Five of the six dolphins were tracked for 1-2 days at distances up to 24 km (IATTC 1993), providing data on movement, speed, respiration/dive-time intervals, and general behavior. The two TDRs were recovered after the animals had been at liberty for 25 and 44.5 hours.

On 22 November 1992 following Set 7, the first dolphin tracking effort was initiated. A 177 cm fused female northern offshore spotted dolphin (D2), tagged during Set 7, was released at 1300 hours. D2 was tracked until 0855 on 23 November 1992 when the animal was recaptured with approximately 300 other dolphins during Set 8. Two more dolphins (D3 and D4) were tagged during Set 8 and all three tagged spotted dolphins were released with the rest of the captured dolphins and tuna. Two of the tagged dolphins (D2 and D3) traveled in one direction with one group of spotted dolphins and both were tracked by the *McArthur* and one of its' launches. The other tagged dolphin (D4) was associated with another group of spotted dolphins that traveled in the opposite direction and was tracked by a second launch. Telemetry packages (sonic tags) were placed on three yellowfin tuna captured during Set 8. Two tuna were outfitted with depth-sensitive transmitters operating on the same 60 kHz frequency, and a third tuna's transmitter operated at the 69 kHz frequency. All the dolphins and about 13 of the estimated 15 tons of tuna were released during backdown. The launches began tracking two of the tagged tuna, but became confused when these two fish, bearing transmitters at the same frequency (60 kHz), swam in different directions. Both signals were lost before a heading could be determined, and the third tagged tuna (69 kHz) was never located. Once the tuna signals were lost, both of the *McArthur's* launches began tracking the dolphins associated with D2 and D3, and the *Nicole K* assumed tracking the dolphins associated with D4 at 1400 hours. Late in the afternoon, the *McArthur* stopped tracking D2 and D3, traveled approximately 30 miles to the *Nicole K*, and assumed tracking of D4 at 2100 hours.

D4, a 187 cm fused female northern offshore spotted dolphin, and its associated dolphins were tracked throughout the night. The *Nicole* K attempted to recapture the school at 0812 on November 24, 1992, but the animals dispersed. Tracking continued until 1030 when the dolphin school associated with D4 was recaptured during Set 9. Another spotted dolphin was tagged (D5) and two more yellowfin tuna were lance-tagged inside the net. The skipper was unsuccessful in releasing the tagged tuna during the backdown procedure, but both dolphins (D4 and D5) were released. Although none of the tuna were tracked, both dolphins were tracked by the *McArthur* and its launches beginning at 1330 hours. Tracking of both dolphins continued throughout the night until the signal for D4 was lost at 0400 hours on November 25, 1992. While the *McArthur* tracked D5 and the associated 700-800 dolphins through the day, the *Nicole K's* helicopter located another school of 1000-1500 dolphins associated with the tagged dolphin D3 at 0852, but the latter school was not followed.

D5 was tracked and recaptured on November 26, 1992 at 0853 during Set 10. The telemetry package and TDR attached to the animal were recovered and the animal released. A fused female northern offshore spotted dolphin (D6) was captured, tagged, and released at 1130 hours, but only tracked for a short period before the *McArthur* abandoned the effort. The *Nicole K's* helicopter successfully located the a previously tagged animal (D3), equipped with a TDR, and the *McArthur* and *Nicole K* both proceeded towards D3's location. At 1526, the *Nicole K* captured 7 of 15 dolphins associated D3, but not D3 itself during Set 11. Deteriorating weather prevented further attempts to capture the tagged animals during the remainder of the cruise period.

In addition to the tagging and tracking studies on dolphins and tuna, a total of 152 yellowfin tuna were sampled during sets 2-4, 8-10, and 12 (Figure 1) and processed aboard the *NICOLE K*. During the tuna sampling sessions each yellowfin tuna's fork length, sex, and a general description of stomach contents was recorded. Scientists also captured, measured, tagged, and released 18 olive ridley sea turtles, *Lepidochelys olivacea*, including one previously tagged individual, during the 30-day charter period. Unfortunately, the type of large bird flocks typically associated with tuna/dolphin aggregations were seldom encountered, and opportunities to study seabird flock behavior and feeding habits during the 30-day charter period were rare.

<u>Cruise II (1993)</u>. With the assistance of the U.S. Department of State, NMFS provided partial funding to the IATTC to facilitate a second tuna/dolphin tracking study during the fall of 1993 (PO 40ABNF400246; $115,000). The study was conducted by the IATTC in cooperation with

the NMFS and the University of Hawaii, with participation by biologists from the Universidad Nacional de Costa Rica (UNCR) and Mexico's Programa Nacional para el Aprovechamiento del Atún y Protección de los Delfines (PNAAPD).

Thirty days of ship time were available aboard the NOAA Research vessel *McArthur* during 6 November 1993 - 5 December 1993. The *CONVEMAR*, a Mexican tuna purse-seiner, was chartered by the IATTC beginning on 6 November 1993. Details concerning the contract can be requested from the IATTC. At our request, the U.S. Department of State obtained permits to conduct scientific research in national waters from the governments of Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, and Panama. As Chief Scientist, the IATTC's Dr. Michael D. Scott obtained a U.S. permit to capture and tag dolphins in accordance with the U.S. Marine Mammal Protection Act of 1972.

Three oceanic areas were identified for possible operations based upon an analysis of historical data indicating calm seas and the presence of tuna and dolphin during November. Although tuna seiners routinely conduct fishing operations in sea states up to Beaufort 4, the *McArthur's* auxiliary launches (used for tracking tuna) could only be deployed and recovered under relatively calm seas of Beaufort 3 or less. During the 30-day charter period, both vessels traveled among all three areas, but all the sets and tracking operations occurred in a region of ocean delineated by 18-19° North latitude to 103-105° West longitude (Figure 2).

Ancillary projects were again performed by scientists aboard both the *CONVEMAR* and the *McArthur* on an opportunistic basis to investigate further the mechanisms and nature of the tuna/dolphin association and gather information on other marine species including sea turtles, sharks, billfish, flying fish, and birds. The *McArthur's* flying bridge was equipped with three pairs of mounted Fujinon 25x binoculars that were used to locate cues that led to marine mammal sightings.

The tuna purse-seine vessel's primary function was to locate, capture, and release tagged spotted dolphins and yellowfin tuna for subsequent tracking by the *McArthur* and its launches. Procedures to handle both the tuna and dolphins inside the net were the same as developed during the 1992 cruise. Following the release of the dolphins and tuna, the dolphins were tracked from the *McArthur*. The *McArthur's* launches (AR-4 and AR-3) were the primary tracking platforms for the tuna. For safety reasons, when tagged tunas and dolphins separated by more than 8-10 miles, the *CONVEMAR* was used to track dolphins, so the *McArthur* could readily render assistance to its launches should the need arise. The purse-seine vessel's helicopter was used to observe dolphin herds, estimate herd size, and detect the presence of tuna with the dolphins. Generally, the purse-seine vessel maintained a distance of 10-20 miles from the tracked animals when not actively involved with tracking effort.

<u>Results</u>. Five northern offshore spotted dolphins were captured, equipped with telemetry packages, released, and subsequently tracked during five of the 18 sets (sets 4, 7, 11, 16, and 17) made on dolphins during the cruise (Figure 2). These five animals (D7- D11) were tracked from

one to four days. Four of the five dolphins (D7-D10) were also equipped with TDRs, of which three were recovered after the animals were at liberty for periods ranging from 18 hours to over four days (IATTC 1994, Armstrong 1994).

Six yellowfin tuna (T1-T6) were tagged during three sets (7, 11, and 17) using one of three types of sonic transmitters. One type of tag provided horizontal movement information exclusively at a maximum range of 0.5 - 0.75nm. The two other types both transmitted ambient water pressure data (which allowed determination of swimming depth) and location (range and bearing). Of these two, one had a maximum range of 0.75 - 1.0 nm, and the other a maximum range of 0.5 - .75 nm. Although two tuna were tagged in each of three sets, only one of the two tuna were tracked from each set. Three of the tagged tunas (T1:Set7, T3:Set 11, T5:Set17) were continuously tracked for thirty-one, one, and eight hours, respectively.

Scientists recorded the species and distribution of seabirds observed during marine mammal sighting effort, but no seabirds were collected. Observations on the distribution and species of sea turtles were also recorded during marine mammal sighting effort. Biopsy samples were collected using a low-powered crossbow to obtain a small piece of skin from cetaceans that rode the bow wave of the research vessel. Flying fish were collected using dip nets at night on several occasions, including two specimens of unidentified juvenile four-wing flying fish. Various species of fish were caught on an opportunistic basis by hook and line and their stomach contents examined by Dr. Robert Olson (IATTC). The PNAADP scientists conducted three acoustic and six bubble-curtain experiments aboard the *CONVEMAR* during the cruise. Oceanographic data were collected throughout the survey. Continuous data on temperature and salinity of surface water were collected and recorded digitally. A SEACAT mini-CTD or an XBT was deployed from the *McArthur* at four-hour intervals during tracking operations.

<u>Discussion</u>. Dr. Michael Scott (IATTC) was Chief Scientist and Wesley Armstrong (NMFS) was the Field Operation Leader during both tracking cruises. Both contributed much of the information and figures included in this section of the report (IATTC 1993, 1994; Armstrong 1993, 1994; Scott et al., in prep).

During the two cruises, three yellowfin tuna carrying depth-sensitive transmitters were tracked for 1 hour, 8 hours, and 31 hours, ten dolphins were tracked for periods ranging from 1 to over 4 days, and five of the ten tracked dolphins were recaptured and their TDRs recovered after having been followed for periods of 18.5, 25, 44.5, and 48 hours to over four days. These data provide a history of the individual movements, preferred swimming depths, and dive duration and frequency for each animal. Although the sample is small, these data also allow comparison between the horizontal and vertical movements of tuna and dolphins.

Analysis of the 1992 and 1993 TDR data from the five TDR-tagged spotted dolphins show that these animals made their deepest dives at night, possibly to feed on organisms in the deep scattering layer as the layer migrates towards the surface during darkness (Figures 3a-d). Deep dives were most frequent just after sunset and just before sunrise, with the deepest dive recorded at 203 meters. During the day, these five dolphins typically dove no deeper than 20 meters.

Data obtained from the three tracked tuna show a very different pattern of depth preference (Figures 3a-d). These tuna swam in the mixed layer at depths of approximately 35-40 meters during the day. This depth was just above the upper region of the existing thermocline and below the typical 20-meter depth to which the dolphins dove. Shortly after dusk, the tuna narrowed their vertical movements to depths nearer the surface, typically around 25 meters, at the same time the dolphins began diving deeper. The deepest swimming depth recorded for tuna was 110 meters during daylight.

During the 31-hour track of one 60-pound yellowfin tuna (T1), the fish followed the dolphins with which it was released for about an hour (Figure 4), but separated shortly after noon. T1 was not observed with dolphins during the remainder of the 31-hour track even though several groups of dolphins were observed close to the tuna's location. During another 8-hour track, a tagged 20-pound tuna (T5) was not released with a group of dolphins, but was subsequently located and then tracked with a dolphin herd late in the day. These data suggest the association of yellowfin tuna and spotted dolphin is neither permanent nor obligatory (IATTC 1993).

These data indicate some vertical separation between associated spotted dolphins and yellowfin tuna during the day, and may reflect a preference by tuna for the upper thermocline region. The relatively shallow thermocline depths in the ETP may result in greater encounters by yellowfin tuna schools swimming near the thermocline with surface-breathing dolphins. Conversely, in areas where the thermocline is deeper, encounter rates of tuna oriented with the thermocline and surface-breathing dolphins would be less. The existence of a vertical separation may allow development of fishing methods to separate tuna from dolphins. If the tuna/dolphin association is not permanent, there may be schools of yellowfin tuna not associated with dolphins, in areas where dolphin-fishing occurs.

Tuna Oceanography

During 1992, funds were provided for a cooperative research project between NMFS and IATTC to study correlations between yellowfin tuna catch rates and environmental factors in the ETP (PO ABNF202035; $35,000). The work was one of the four high priority proposals recommended by the first research planning workshop (DeMaster 1992). Purse-seine catches have been shown to be related to thermocline depth (Green 1967), but this report did not provide an analysis of fish size or fishing method (school fishing, log fishing, or dolphin fishing). Dr. Paul Fiedler's (NMFS) efforts have been directed at analyzing and interpreting oceanographic environmental data in relation to dolphin distribution (Fiedler 1992a, 1992b), and Mr. Richard Punsly's (IATTC) have been directed at analyzing and interpreting yellowfin tuna catches in the ETP (Punsly 1987, Punsly et al. 1994).

These collaborating researchers are attempting to determine which physical oceanographic factors, if any, are correlated with yellowfin tuna abundance and geographic distribution. They have also investigated factors that might influence the vertical distribution of tuna schools, and hence, their vulnerability to purse-seine gear. Successful correlation of oceanographic factors with tuna abundance, distribution, and vulnerability could ultimately lead to identification of areas of greater tuna abundance using remote sensing platforms. The ability to locate such areas, especially if they involve tuna not associated with dolphins, could lead to an efficient and economic alternative to dolphin fishing (Punsly and Fiedler, submitted ICES Journal for Marine Science).

Environmental data and yellowfin tuna catch data from 1980-1990 were analyzed using General Linear Models (GLMs). The GLM approach was used to estimate the effect of environmental factors on catch rates (catch-per-set and hours-of-search-time-between sets) for purse-seine vessels. Data were stratified by 2-by-2 degree quadrangles and months. Means were calculated for four measures related to vertical stratification of sea temperature and seven measures related to wind (IATTC 1994).

Preliminary results indicate marked differences between the means for most environmental variables for 2-degree-quadrangle strata with, and without, all types of purse-seine effort (dolphin, school fish, and log fishing). Generally, areas with a shallower thermocline had more purse-seine fishing effort than areas with a deeper thermocline. However, for those quadrangle strata with fishing effort, although there were some differences between the means of environmental variables associated with, and without, yellowfin tuna catches, the differences between means were not as great as the means associated with season or area.

The authors found low but significant correlations between the environmental variables they examined and yellowfin tuna catches made by purse-seiners. Non-dolphin tuna catches occurred over a wider range of environmental conditions (e.g., sea surface temperature) than did dolphin-associated catches, although the geographic range of non-dolphin catches was restricted during most months. Analyses of the variance in yellowfin catch rates indicated that geographic location and time of year explained more variation (~30%) than did any combination of environmental variables. The authors note that some particular areas of the ETP exhibited higher catch rates of non-dolphin-associated large (>7.5kg) yellowfin tuna, but overall catches of these unassociated fish are less closely tied to the measured oceanographic variables than were dolphin-associated yellowfin tuna catch rates. The authors conclude that "...these occasional high catch rates suggest that it might be possible to improve fishing methods and deployment of effort to increase fishing success for yellowfin >7.5 kg not associated with dolphins, especially in the southern regions of the ETP." Recent catch records (1995-1996) from the ETP fishery appear to corroborate these predictions, and these new data are being incorporated into a revised manuscript.

Food Habits

Researchers have suggested that the association of dolphins and yellowfin tuna in the ETP may be food-based; feeding on a common prey, or prey assemblages (Perrin et al. 1973). In 1992, NMFS provided funds to IATTC for Dr. Robert Olson to conduct a study to examine the food habits and trophic dynamics of co-occurring yellowfin tuna, dolphins, and other large predators (PO 40ABNF202034; $133,000).

This study was one of the four high priority proposals identified in our first research planning workshop (DeMaster 1992). The study's purpose is to: 1) examine stomach contents of yellowfin and dolphins caught together in the same purse-seine sets, and the stomach contents of yellowfin and other predators caught in logfish and schoolfish sets in the same areas and at the same times, and 2) conduct an analyses of stable carbon and nitrogen isotopes in these animals' tissues to both provide a second independent indicator of diet overlap, and provide a measure of trophic overlap that is integrated over a longer time than that indicated by stomach contents. Both muscle and liver tissues were sampled for analysis of isotope abundance of 12C, 13C, 14N, and 15N in the predators sampled from four selected purse-seine sets, two dolphin sets, and two log sets.

NMFS received a preliminary report from the authors during November 1995, although the project's progress is discussed in IATTC annual reports (IATTC 1994, 1995). Only a preliminary examination of the food habits of associated dolphin and yellowfin tuna stomachs (taken from the same purse-seine set) is presented in their report. Further analysis of these data, and similar examination of data from schoolfish and log sets, will be forthcoming. Results from the stable isotope analysis of 200 samples are not yet available. With their permission we provide the following synopsis of efforts to date as reported in Olson and Magana (1995).

Data were collected by IATTC observers aboard tuna vessels fishing in international waters or within the jurisdictions of Mexico, Venezuela, Columbia, and Panama. Data collection forms, materials, and procedures were developed by IATTC and distributed to observers during training workshops. A video was also created to demonstrate sampling methods. For sets in which 3 or more dolphins were killed, samples were taken from up to 25 dolphins, 25 yellowfin tuna, and up to 25 of each of the other fishes and mammals captured. Similar sample sizes were obtained for yellowfin tuna and other predators caught in log sets and schoolfish sets.

Samples from the dolphins and most of the bycatch were taken at sea. Tunas were either sampled at sea or marked immediately after capture, placed in the fish holds, and sampled after unloading. The study was designed to examine trophic dynamics throughout the year and the entire range of the fishery.

Stomach samples were collected during 327 sets on 183 cruises between June 1992 and September 1994. Dolphin sets (89 sets) were sampled across the geographic range of the fishery, while the 103 schoolfish sets were more coastal, and the 93 logfish sets sampled were primarily from the southern range of the fishery. Stomach and tissue samples were obtained from nearly 8,300 individuals. Although 580 dolphin stomachs and 4,830 yellowfin tuna stomachs were obtained, sample sizes of 25 individuals per set were only obtained for yellowfin tuna, primarily because of the great reduction in dolphin mortality that was evident during the period (IATTC 1994).

Stomach samples from 225 spotted dolphins, 175 spinner dolphins, and 1,824 yellowfin tuna were obtained from the 89 dolphin sets. Food remains were found in the stomachs of approximately 70-75% of each of these three groups. The authors stratified data by the time sets were initiated (0600-0900 hours, 0900-1200 hours, 1200-1500 hours, and 1500-1800 hours), and assigned stomach contents to one of three categories: 1) recently obtained prey ("early digestion"), 2) "advance digested" prey occupying 50% or more of the stomach volume, and 3) empty stomachs or stomach with less than 50 % of the stomach volume occupied by "advance digested" prey.

Olson and Magana (1995) state: "The diurnal periodicity of stomach fullness and prey degree of digestion indicate that spotted and spinner dolphins fed very little in daytime. Recently eaten prey and "full" stomachs (>50% full) declined steadily in occurrence from sunrise to sunset, suggesting that the nighttime may be the principal feeding time of the dolphins. While yellowfin may also eat cephalopods at night ... daytime feeding is clearly more important for yellowfin than for dolphins. In the early morning, the fresh prey in the dolphin and yellowfin stomachs were dissimilar, suggesting that feeding took place in different places and/or before the animals were associated, either very early in the morning or at night. It is unlikely that incidental feeding on shared prey taxa in the afternoon ... explains the basis for maintaining the tuna-dolphin association."

Fish Aggregating Devices (FADs)

Fishermen and scientists alike have long been aware that objects floating in the ocean attract various species of fish. Fish aggregating devices (FADs) have been employed to attract commercially important species of fish in many ocean areas (Gooding and Magnuson 1967, Hunter and Mitchell 1968, Greenblatt 1979, IATTC 1992). Yellowfin tuna, *Thunnus albacares* and skipjack tuna, *Katsuwonus pelamis*, are two commercially important species commonly attracted to floating objects in the Pacific Ocean. Floating objects include both organic materials such as trees, kelp, and dead animals, and man-made objects such as fishing floats, buoys, rope, and wooden packing crates. Although no one knows exactly why floating objects (e.g., FADs) attract fish, the association occurs often enough to warrant into the use of FADs as an alternative to dolphin fishing in the ETP. A thorough description and discussion of joint NMFS and IATTC FADs research during 1990-1992 appears in Young and Armstrong (1992), and subsequent efforts during 1993-1995 in Armstrong and Oliver (1996). These studies are described and summarized below.

<u>Preliminary Drifting FAD study</u>. NMFS and IATTC arranged for the deployment of two identical FADs, each equipped with satellite transmitters, in the ETP fishing area during early 1991. These two FADs were deployed to test the durability of surface buoys, electronic components, and the

practicality of tracking FADs by satellite to provide approximately continuous position information to fishing vessels. Both FADs consisted of blue octagonal surface buoys, six and a half foot in diameter, made of 8" diameter foam-filled PVC pipe. Two vertically mounted PVC tubes on opposite sides of the buoys housed a xenon strobe flasher unit with photocell controllers and the satellite electronics and battery supply. The subsurface arrays for both FADs consisted of four polypropylene lines tied onto the surface platform at equal intervals, and connected to a 60-pound lead ballast weight at a depth of 25 feet. Thirty-inch cable ties were attached to the lines at regular intervals to increase the surface area of potential habitat for smaller organisms. Positions and estimates of drift transmitted to vessels searching for the FADs were fairly accurate (Young and Armstrong 1992). A set on one FAD was within 3 km of the position provided by Service ARGOS. This position data was three hours old when the set was made. A sighting of a FAD was within 30 km of the position reported by satellite. This position data was about 96 hours old at the time of the sighting. We are unaware of any tuna taken in association with either of these FADs.

Besides these two drifting FADs, seven other FADs of various designs (all with subsurface sea kite arrays), were deployed in the ETP by several purse-seine skippers. Sea kites are pyramidal structures, measuring six feet on a side, constructed as a fiberglass pole frame with yellow "rip-stop" nylon walls. Kites were attached at regular intervals to a weighted monofilament mainline suspended in the water from the surface buoy of the FAD. The pyramid shape of the kite provides a relatively large surface area as potential habitat for smaller organisms that, in some cases, may be the only permanent residents on floating debris (Hunter and Mitchell 1968). These seven FADs were variously deployed for periods of 2 to 19 days and sporadically visited by the fishing vessels. While some accumulations of forage fish, barnacles, and crabs were reported, no tuna were observed (Young and Armstrong 1992).

That oceanographic buoys attract fish has been noted by NMFS observers and purse-seine fishermen (Young and Armstrong 1992). Positions of low profile, wave-resistant and wind-resistant drifting current measuring oceanographic buoys were provided by Atlantic Oceanographic Metrology Laboratory to SWFSC through OMNET twice weekly during 1991-1992. These data were dispensed to interested purse-seine skippers and owners on a weekly basis. Three sets were made on drifting current buoys and significant quantities of tuna were caught.

<u>Bumblebee/IATTC/NMFS Drifting FAD Project</u>. During 1991, NMFS cooperated with IATTC and Bumblebee Seafoods Incorporated in an experiment involving 30 drifting FADs. Bumblebee Seafoods Incorporated provided IATTC approximately $240,000 for the purchase of materials, FAD construction and deployment, satellite services, and analysis.

In July of 1991, 30 FADs were constructed incorporating three replicate FADs of each of 10 different designs. The FADs were equipped with tracking and locating devices and deployed by tuna purse-seiners in the ETP. The designs ranged from surface buoys only to surface buoys with arrays descending to 100 meters in depth. One FAD in each group was equipped with a satellite transmitter that broadcast positions through the ARGOS satellite system. The other two in each group were equipped with selective-calling (SELCALL) medium-wave radio buoys which operate only when activated by a vessel's signal generator. The satellite transmitters provided positions that were accurate to within a kilometer or less. Position data could be accessed daily through Service ARGOS satellite system. SELCALL radio-buoys can be tracked by vessels at distances up to 200 kilometers.

The FADs were deployed 1,000 miles offshore of Mexico in an area from 9°N to 11°N between 121°W and 124°W (Figures 5a-j). This area and the region to the West, where the FADs were expected to drift, are the traditional fishing grounds for large yellowfin tuna caught in association with dolphins. IATTC's historical catch data also indicated that adjacent areas, although not especially rich in natural logs, had produced larger than average yellowfin from log sets. All 30 FADs were launched within a 24-hour period. The deployment around the 10° N latitude appeared to overlap the north equatorial countercurrent and the north equatorial current (Figure 6). Several of the FADs drifted in a northwesterly direction, while others positioned only a short distance away drifted to the Southeast. Those drifting to the Northwest eventually turned to the West. Those drifting to the Southeast circled around to the Northeast, and then to the West as they encountered a westerly current near 12° N latitude. Shortly after the 30 FADs were launched a series of tropical storms and hurricanes passed through the deployment area. These storms forced the fishermen to seek safer waters to the East (where excellent fishing developed), and rapidly pushed the FADs westward out of the traditional fishing grounds. These events resulted in only a limited number of visits to the FADs by fishing vessels, although we continued to track, and report, their locations for several months.

The few sets made on these FADs reported only small catches of tuna. The first failure of a satellite transmitter was recorded on November 6, 1991 (106 days after deployment), followed by the failure of a second satellite transmitter on November 8, 1991. We ceased providing positions on September 28, 1992 because all the remaining groups of FADs were well west of the fishing grounds.

Of the eight satellite transmitters still functioning as of September 1992, all but the most easterly of the FADs had drifted beyond the traditional fishing areas of the ETP. Last known position and status of the platforms were obtained Service ARGOS on 20 April 1993, and indicated a continued westward movement well outside the fishing grounds. A Spar-type, SELCALL-radio- equipped FAD (Number 24) deployed on July 23, 1991 was recovered by a fisherman from the Province of Southern Leyte in the Republic of the Philippines in on February 21, 1993, having traveled a linear distance of approximately 6,700 nautical miles during 580 days (IATTC 1994). The captain of the boat reported to IATTC the radio antenna had been removed or broken off and there was no subsurface array attached to the buoy. He observed barnacles and moss growing on the buoy, but he did not see any fish associated with the FAD. The digital, daily position data obtained for these satellite-equipped FADs have been archived at the SWFSC.

Group Number	Date of last contact	1993 Julian Day	Position	Status
1	March 3, 1993	62	20.123 N - 168.367 W	Active
3	March 3, 1993	62	9.423 N - 170.226 E	Active
4	September 30, 1992		11.567 N - 158.416 E	Inactive
5	March 3, 1993	62	8.121 N - 173.057 E	Active
6	February 25, 1993	56	17.043 N - 131.078 E	Inactive
9	January 3, 1993	3	17.590 N - 139.715 E	Inactive
10	September 5, 1992		11.319 N - 164.523 E	Inactive
7	January 19, 1993	19	12.654 N - 163.580 E	Inactive

A second deployment of 30 FADs was part of the original plan, but the expenses of constructing the elaborate phase 1 designs and monitoring the FAD locations with the ARGOS satellite system, and the dearth of visits by tunaboats to these FADs led IATTC to abandon the second phase of the study.

Anchored Oceanographic Buoys. As part of NOAA's Tropical Ocean Global Atmosphere (TOGA), a Tropical Atmosphere Ocean (TAO) array of 69 anchored platforms was completed in 1994 (Freitag et al., 1995). These platforms are moored every 2 to 3 degrees of latitude between 8 North and 8 South, along lines separated by 10 to 15 degrees of longitude, between 95 West and 137 East longitude (Figure 7). The location and status of these moorings are published in the U.S. Coast Guards Notice to Mariners. Each platform collects a variety of surface and subsurface oceanographic and environmental data, transmitting the results daily by way of the ARGOS Service satellite system. The TAO project is a joint effort of the United States, Japan, Korea, Taiwan, and France to develop an ocean observing system for studies of ocean-atmosphere interactions. The TAO Project Office is located at NOAA's Pacific Marine Environmental Laboratory in Seattle, Washington. Information on the location, condition, and procedures for operating in the vicinity of these moorings are available at the following address:

TOGA-TAO Project Office
NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
Seattle, WA 98115

Phone: 206-526-6743
Fax: 206-526-6744
OMNET/Telemail: TAO.PMEL
TELEX: 740 8888 (OCRD UC)

Positions of some of the TAO anchored platforms were provided to a few cooperating fishermen before 1993, who subsequently reported tuna catches near them. Anecdotal reports continue to identify these structures as aggregating large concentrations of tuna. Currently, NMFS is not actively promoting these buoys as FADs because of concerns that fishing on or near these structures could result in damage to the buoy or mooring. The TAO array of anchored platforms, especially those resident in the ETP, represent an opportunity for a focused research experiment on the potential for FADs to aggregate large tuna, and to investigate the fauna and flora community development. What is needed is dedicated time with a research vessel or, preferably, a tuna purse-seine vessel carrying a scientific staff.

NMFS-deployed Anchored FADs. As an alternative to research using the TAO array of platforms, we developed a plan to deploy anchored FADs in an area closer to the U.S. (e.g., Revillagigedo Islands), and which is visited by long-range sportfishing vessels. These islands are noted for the large yellowfin tuna captured by sport fishermen and could provide a relative inexpensive research opportunity to determine if pelagic, anchored FADs are capable of attracting large yellowfin, bigeye, and skipjack tuna in economically attractive quantities. The cost to construct and deploy anchored FADs on the high seas would range from $1,000 to $6,000 per unit. The wide range in cost estimates results from the design and quality of materials used to construct various components of an anchored FAD. Once in place, we proposed to conduct studies in and around these platforms to investigate the fauna and flora community development, and conduct systematic surveys to document the presence of tuna schools. This project would require the use of a research vessel or a commercial tuna purse-seine vessel to deploy the gear. To facilitate visits and sets on these FADs by fishing vessels, we would notify skippers in the ETP tuna fleet and sports-fishing vessels of its location and request that they provide NMFS with data on their observations and catch.

The reliability of a mooring is directly correlated to the quality of its design and components. A surface buoy must be buoyant enough to counteract weight of chain-line and hardware holding it on the bottom. The surface platform should be easily sighted by eye and detected by radar so commercial fishing vessels and chartered fishing boats can check the FAD when they are in the area.

Surface buoys can be as simple as two sheets of 3/4 inch water- sealed plywood with foam sandwiched between the two sheets. This type of buoy would cost around $300 to construct. If buoys were constructed before departure, they could be easily stored on the ship and would be relatively simple to deploy. A surplus foam filled 9-ft. AOML spar buoy is in storage in San Diego and available for use at no cost. A SELCALL radio buoy can be housed inside the upper section of the buoy and eliminate the need to tether a radio buoy to the surface platform. In the South Pacific fishermen use large fuel or soap drums filled with foam that are welded together and reinforced with steel rods. This is a relatively low cost option but it would require considerable deck space aboard a research vessel before deployment compared to the other options. Atlas buoys measuring 92 inches in diameter, with stainless steel bridles, are available from PMEL in Seattle for no cost except for shipping from Seattle to San Diego.

The cost of mooring line and connecting hardware with sufficient tensile strength to secure a FAD in 1000 meters of water ranges from $320 (used) to $800 (new) per FAD.

Galvanized connecting hardware, chain-line, and anchor systems become increasingly expensive depending on the size of the hardware and the sophistication of the mooring design.

NMFS Cooperative FAD Project. In December of 1992, the owner/captain of the vessel *Connie Jean,* Richard Stephenson contacted us and expressed interest in using inexpensive materials to construct FADs that he would anchor in waters 140- 500 fathoms deep. He agreed to provide materials to construct surface platforms and anchors; NMFS supplied enough ground line to moor up to five FADs. We bought 3,500 fathoms of used, floating, 22-mm nylon line (at 20% of the cost of new line) for Captain Stephenson's use to anchor FADs ($1,750). In exchange for providing the anchor line, Captain Stephenson agreed to maintain a data collection log we developed to document construction, deployment, visits, sets, and catch on both his anchored and drifting FAD deployments.

Captain Stephenson's anchored FADs consisted of one of two designs. The first design incorporated a multi-chambered metal- surface buoy with a truck tire affixed to the bottom. Several loops of steel cable are threaded through the middle of the tire, and this cable was then spliced and clamped to 100-meters of steel cable attached to a large swivel. Mooring line joined to the swivel leads to the bottom and was connected to a large swivel coupled to the anchor's bridle. Anchors were constructed of two 55-gallon drums filled with concrete (Figure 8). The alternative design incorporated all the features of the first design plus a detachable buoy equipped with a generator and lights. Several hours before sunrise this buoy can be disconnected from the anchored surface buoy and slowly towed away by a speedboat so a set can be made away from the mooring.

Captain Stephenson's drifting FADs are described in detail in Armstrong and Oliver (1996). His surface platforms consisted of square rafts composed of 15-foot, 4-5 inch diameter bamboo poles, lashed together with twine. Various amounts of old purse-seine netting were weighted and attached to the platform to form an underwater canopy hanging 10 fathoms deep. Buckets of fish waste and chemical light sources were often weighted and attached to the platforms (Figure 9). He generally deployed 3-10 platforms in a 2-3 mile area, with one platform equipped with a radio beacon to aid in locating the FAD group.

Captain Stephenson deployed and fished drifting FADs in waters offshore of Ecuador and Peru during February and March 1994 (35 separate deployments), and two anchored FADs in the Gulf of Panama during April and May 1994. Data on the design, construction, and deployments of Captain Stephenson's surface platform moorings are reported in Armstrong and Oliver (1996).

A second U.S. skipper (who wishes to remain anonymous) also agreed to participate in our investigations. We provided five Ryokuseisha SV-CL3B SELCALL radio buoys ($7,500) during 1993 in exchange for information about construction, deployment, visits, and sets on drifting FADs assembled during his "dolphin-safe" fishing trips. He too constructs drifting FADs out of surplus materials found aboard his vessel including old net webbing, used corkline, balloon floats, scrap lumber, and wooden crates and pallets. He incorporates "seasoned" flotsam found at sea into the structure: logs, driftwood, dead marine mammals, billfish, and abandoned or discarded fishing gear such as longline floats, tangled gillnets, plywood, and floating line.

A general FAD design used frequently by this skipper consists of two four-meter-long two-by-fours tied together with net twine. Used corks are tied to the top of the boards. Net webbing, approximately four meters wide and twelve meters deep, is connected to the bottom of the two-by-fours. This design creates a curtain that can be rolled up for storage aboard the vessel and simplifies deployment. A plastic, 55-gallon drum filled with discarded fish is connected to one end of the two-by-fours and a radio buoy is attached to this bait bucket with 20 meters of line (Figure 10). FADs are deployed as a group in areas where signs of tuna are detected, with at least one FAD in each group equipped with a radio beacon. This Captain deployed 20 FADs during two trips, and we received data from both trips during 1994.

Results. Drifting FADs were successfully used by both participating skippers to catch tuna in the ETP. Although Stephenson's tuna catch associated with his Group 2 and Group 3 drifting FADs was limited to 225 tons in three sets before he headed to port to unload, the unverified (by us) reports he received from other fishermen after his departure indicate that these FAD-Groups were very productive. Tuna catches by three vessels totaled 750 tons on Group 2 FADs and catches from six vessels totaled 1,490 tons on Group 3 FADs (Armstrong and Oliver 1996). The second skipper's fishing effort on FADs during his second trip was significantly more productive than the first trip. His total tuna catch associated with Trip-1 drifting FADs ranged from 0.25 to 16 tons per set with a mean value of 5.4 tons per set, while the catch associated with drifting FADs during Trip-2 ranged from 30 - 190 tons per set with a mean value of 84.6 tons per set.

Both skippers used a basic design for their drifting FADs that employed a surface-platform constructed entirely with buoyant materials. Each skipper suspended net webbing or other available materials to the FADs' surface-platform that hangs below the water surface and is believed to attract fish. While more elaborate FAD designs have been used by these skippers, they believe the simpler designs using relatively inexpensive materials are equally effective and reduce their monetary losses associated with the disappearance, vandalism or piracy of unattended fishing gear. Skippers also reported that the ease of deployment, recovery, and storage of the FADs was important to the safety of their crew.

Both reported that location of deployment is more important than focusing an extraordinary effort on "gizmos" that make FADs "more attractive" to tuna. FADs were deployed in regions where skippers felt there were good fish signs. Most skippers base these decisions on detailed records of past fishing effort recorded on navigation charts, computers, and from information received on a daily basis at sea from other fishermen. Skippers check an area for "signs of fish" before deploying FADs and again when FADs are visited. Tuna observed jumping, creating a "shiner" (reflection off the side of a tuna), or a surface disturbance known as a "breezer" are all regarded as good fish signs. Large numbers of seabirds, especially frigate birds, *Fregetta sp*., and booby birds, *Sula sp*., flying above a log are generally a reliable clue that tuna may be in the area, as are large numbers of baitfish, dolphin fish, and sharks swimming near flotsam. These methods of assessment are effective at a very local level, but the ETP tuna fishing grounds encompass a huge area. Therefore, it would be desirable for fishermen to obtain larger scale assessments of oceanographic conditions and trends that could allow them to become more efficient and achieve higher productivity fishing FADs.

Armstrong and Oliver (1996) examined IATTC Flotsam Information Record data from nine fishing trips and describe 94 visits that included 69 sets associated with FADs made by four purse-seine vessels (nine trips) during the period October 24, 1993, to March 12, 1994. Sets associated with these FADs produced total catches of 2,601.5 tons of skipjack tuna with 312.5 tons discarded, 432 tons of yellowfin tuna with 36 tons discarded, and 1,743 tons of bigeye tuna with 69 tons discarded. The total combined catch for these sets was 4,210.5 tons of tuna with 417.5 tons discarded. Besides the sets made on inexpensive FADs, three of the four vessels encountered anchored NOAA Atlas weather buoys in the area, and during four sets captured 144 tons of skipjack tuna and 602 tons of bigeye tuna, all of which was retained (0 tons discarded).

It is clear that FADs constructed of inexpensive materials can quickly aggregate large amounts of tuna as evidenced by the catch of 225 tons of tuna in 3 sets made by Stephenson on drifting FADs within 5-15 days after deployment, and the 365 tons captured by the second skipper during four sets made 6-12 days after deployment. While yellowfin and skipjack tuna weights varied greatly in the reported catches (1.8 - 22.7 kg), most of the reported bigeye tuna catches involved fish weighing more than 20 kg. Historically, annual bigeye tuna catches in the purse-seine fishery have been small, averaging 5,738 tons for the period 1979-1993 (IATTC 1995). However, during both 1994 and 1995 purse- seiners fishing on FADs captured over 30,000 tons of bigeye tuna each year, primarily in the area bounded by latitudes 5N - 10S and longitudes 85W - 110W (IATTC 1995, 1996).

Although large yellowfin tuna have been caught in association with FADs, historically, most FAD-caught yellowfin is smaller than those caught in association with dolphins. Utilization of drifting FADs in areas generally categorized by fishermen as "dolphin-fishing areas" could potentially aggregate commercial quantities of the larger (>9.1 kg) tunas normally found in association with dolphins, but directed studies are needed. During 1994 and 1995, fishermen have dramatically increased their catches of bigeye tuna by deploying drifting FADs in particular areas and detecting the deeper swimming fish with sonar. It is unclear if these catches represent a newly discovered resource of tunas or an additional take from what has historically been a longline fishery resource. However, the use of FADs to aggregate and capture these bigeye tuna suggest that FADs may provide a potential alternative to fishing on dolphins, and evidence that FADs may be able to aggregate larger yellowfin tuna if deployed in areas and times when these fish are known to be present.

Recent Efforts

NMFS' efforts on FADs during 1995 and 1996 have been limited to 1) conducting a review of the use of FADs worldwide, 2) continuing to develop contacts with fishermen and researchers with knowledge on FADs, 3) developing proposals to utilize anchored FADs in Mexico's Revillagigedo Islands, and elsewhere, using U.S. long-range sportfishing vessels as research platforms and, 4) conducting a cooperative project with two U.S. tuna vessel captains who have been fishing solely on FADs in the ETP since 1990.

We created a questionnaire for tuna fishermen to solicit advice, stimulate suggestions, and offer critiques of existing and proposed FAD designs to catch mature yellowfin tuna. Questionnaires were distributed at the IATTC Organizational Meeting of the Scientific Advisory Board in San Diego during April of 1993, and mailed to owners and skippers in the U.S. fleet (Armstrong and Oliver 1996).

Lidar

Light Detecting And Ranging (Lidar) systems use a laser to generate a short, high-powered pulse of light. As the pulse of light travels through some medium (atmosphere or water), light is reflected from objects encountered by the laser. Some portion of the reflected light is reflected back towards the light source. This "back scattered light" is collected by a receiving telescope, collimated with lenses and mirrors, and then directed through a narrow-band interference filter to decrease the intensity of ambient light in the medium. The intensity of the back scattered light at the laser wavelength is measured with a photomultipler. The signal from the photodetector is then amplified and directed to devices that display and digitally record signal-intensity versus time-after-laser-pulsing. A large increase in signal-intensity over some ambient level can indicate a sub-surface object. Time-after-laser-pulsing can be used to ascertain the depth of the object.

Locating sub-surface fish with lidar is a technology which could be used 1) during either the day or at night to detect fish schools deeper than current visual methods allow, 2) to detect schools missed because of environmental and human factors (e.g., whitecaps, glare, fatigue, distraction), and 3) may be useful for species identification as well. The optically clear waters encountered in the offshore areas of the eastern tropical Pacific ocean will attenuate light by a factor of 0.001 for every centimeter that the beam travels (Jerlov 1968). A fish-finding lidar is expected to be able to detect fish schools four to six times deeper than the human eye under all conditions. Tuna fishermen we have spoken with indicate they are able to detect schools at 10-20 meter depths under ideal conditions. Therefore, using a lidar should extend the depth of detection to 50-100 meters.

During 1990, the Dolphin-Safe Research Program began investigating the potential for lidar technology to locate sub-surface fish (Squire and Krumboltz 1981, Young and Armstrong 1992). Since 1992, the Dolphin-Safe Program has participated in the development of additional lidar systems, and other airborne optical sensors, to detect subsurface fish schools. We have participated in 1) NOAA's Fisheries Assessment, Science, and Technology Workshop in 1992 (Anon, 1992), and NOAA's Airborne Fishery Assessment Workshop in 1994 (Hunter and Churnside 1995), which resulted in cooperative research with Kaman Aerospace Corporation in development and tests of their FISHEYE airborne imaging lidar fish-finder, 2) two cruises aboard the NOAA ship *David Starr Jordan* during 1994 and 1995 to further lidar development and more recently, 3) collaboration with Arete' Associates and the Office of Naval Research on yet a third lidar system.

<u>NMFS Lidar</u>. Through a series of government contracts, financial assistance from the tuna industry, and extensive cooperation with the owners and crew of the vessel *CAPTAIN VINCENT GANN*, an airborne lidar system was developed, tested, and operated from a helicopter deployed from a commercial tuna purse-seine vessel during normal fishing operations (Grams and Wyman 1993, Oliver et al. 1994). Most of the early reports on the prototype development were marked as propriety by the contractor, but a general description of the efforts appears in Young and Armstrong (1992). The prototype was designed and built using commercially available parts that, with the exception of the $30,000 laser itself, were relatively inexpensive. Developmental costs for this project amounted to approximately $263,000. These expenditures include $138,000 in government contracts, $17,000 provided by Bumblebee Seafoods, Inc., and $108,000 in services provided by Caribbean Marine Service Company and Helicopter Management Company, primarily for the use of a helicopter.

The lidar system incorporated a frequency-doubled Laser Photonics Model YQL-102D Pulsed Nd:YAG laser generating 150 mJ at 1,064 nm and 35 mJ at 532 nm with a pulse width of approximately 15 ns. Two uncoated lenses are used to expand the beam, resulting in a 10% loss in power at each lens and thereby reducing the net laser power output to about 28 mJ. The prototype system weighed approximately 125 kg and was tested and operated for approximately 160 hours aboard a Bell Jet Ranger helicopter between September 17 and October 20, 1992. Operations were conducted on a daily basis with as many as four two-hour flights per day. Multiple passes over the net were performed during seven sets when tuna and other fish were captured. Tuna were repeatedly detected during these sets. A total of 2,002 data files were recorded during 44 of 70 helicopter flights and subsequently analyzed by the contractor (Grams and Wyman 1993).

Although we were disappointed during the field tests by the relatively "slow" fishing which provided only a few opportunities to obtain data on captured fish schools (12 sets in 30 days), the system did detect sub-surface tuna as deep as 17 meters (Figure 11a-b). We believe this was the first time that tuna had been detected using an airborne lidar. During the installation and testing activities in Panama, this lidar was able to detect and display accurate profiles of shallow, turbid, near-shore areas of the sea as deep as 24m (Figure 12a-b). We were encouraged by the results obtained during this project, and recommended a number of modifications to include in any future development of a lidar system to detect tunas (Oliver et al., 1994). We recognize that there are alternative designs for lidar systems that could also meet the needs of fishery applications and these alternative designs are also being explored.

The computer code and an executable copy of the "LIDAR.C" software program (Oliver

1994a, 1994b) with two demonstration data files are available. Execution requires a 386-PC with color VGA and the MSDOS-5.0 operating system. Requests should be directed to the lidar custodian at the SWFSC and include a DOS- formatted 3.5-inch diskette and an addressed, postage-paid return mailer.

Government Funding for NMFS Lidar

Remote Sensing Industries, Inc.:	OSPREY-1	(52ABNF000126; $45,000)
Remote Sensing Industries, Inc.:	OSPREY-1	(40JGNF100433; $ 9,000)
Remote Sensing Industries, Inc.:	OSPREY-2	(43ABNF200692; $24,500)
Remote Sensing Industries, Inc.:	OSPREY-2	(40JGNF210174; $ 4,800)
Grams Environmental Labs:	LIDAR.C	(40JGNF210485; $ 5,340)
Grams Environmental Labs:	LIDAR.C	(43ABNF201797; $24,500)
Laser Photonics, Inc.:	LIDAR.C	(40JGNF210523; $ 5,000)
Delfina Maritime Agency:	LIDAR.C	(40JGNF210486; $ 800)
Team Air Express:	LIDAR.C	(40JGNF210501; $ 467)
Helicopter Management Corp.:	LIDAR.C	(40JGNF210484; $ 6,235)
Remote Sensing Industries, Inc.:	OSPREY-2	(40ABNF300775; $12,000)
		$137,642

<u>NOAA Lidars</u>. NOAA's Office of Oceanic and Atmospheric Research (OAR) hosted a workshop on "Fishery Assessment Science and Technology" at its Wave Propagation Laboratory in Boulder, Colorado on July 27-28, 1992 (Anon. 1992). Members of our program attended this workshop which provided an opportunity for fishery scientists to meet with scientists with technical expertise in remote sensing applications such as lidar, passive imaging, radar, and acoustics. A number of operational and developmental sensors were discussed and fishery research needs were identified.

Participants concluded that the best opportunities for merging sensor capabilities with fishery needs would be to make use of, 1) the U.S. Navy's interest in transferring technology to the civilian sector, 2) technology and expertise available from the former Soviet Union, and 3) joint research efforts. A second workshop was held in Boulder, Colorado on March 22-24, 1994, which focused on potential airborne applications to accomplish fisheries' assessment (Hunter and Churnside 1995). As a result of these workshops, members of our Program have participated in joint research projects on the potential for airborne lidar systems to detection fish schools.

Both workshops addressed potential improvements to the precision and accuracy of aerial fish surveys, including detection, species identification (Churnside and McGillivary, 1991), and biomass estimation, through the use and development of technologies not currently available in fisheries' research. Clearly, detection of yellowfin tuna not associated with dolphins is the first priority for the Dolphin-Safe Program. Species identification by a sensor is desirable, but not as important in the ETP where there are few species of 100cm fish that school in large aggregations (e.g., 15 tons) in the offshore waters. Biomass estimation, although potentially useful for management of yellowfin tuna stocks, is not a priority to our Program.

During 1993, we completed documentation of the NMFS lidar hardware and software and shipped the system to Dr. James Churnside at OAR, who reassembled the system and began experimenting with various modifications designed to allow use of the system from a research vessel. Concurrent with this effort, Drs. Churnside and John Hunter (SWFSC) developed plans for testing a variety of fish-detection sensors during a research cruises aboard the NOAA vessel *David Starr Jordan* in September 1994 and 1995. We arranged for the participation of another airborne lidar system under development by Kaman Aerospace Corporation (Kaman 1995), and the participation of Arete' Associates who were developing an airborne multispectral imaging system under a Commerce Small Business Innovation Research award. Besides the objective of exploring the potential usefulness of each of these three sensors, we hoped to compare performance on both calibration targets and fish schools.

Lidar Cruise I: 1994. During the September 23-30, 1994 cruise (Dotson 1994) the lidar system was suspended over the water from a ship's crane, with the laser beam directed slightly off nadir. Data were collected as the ship passed over oceanographic fronts and fish schools located with the ship's sonar. Both day and nighttime observations were conducted. Aerial fish spotters working with the research vessel were also used to find fish schools and direct the ship to them, as well as to provide an independent estimate of fish species and biomass during daytime operations. A high-speed trawl was used to collect specimens from fish schools that had been sampled by the lidar. On three occasions, submerged targets were deployed and the ship attempted to pass the laser beam over these targets. Passive imaging data were collected from a U.S. Coast Guard helicopter on two days. A Continuous Time Depth (CTD) array with a transmissometer, fluorometer, and scattermeter was used to collect oceanographic data to 200 meters.

As with any first time endeavor, results were mixed. The lidar worked well, but a number of days were needed to adjust the system because of the large surface back scatter resulting from proximity of the laser to the sea's surface (a problem that would be greatly reduced with an airborne sensor). Power adjustments, and other modifications, eventually provided lidar data for comparison with 12 profiles of the physical and optical properties of seawater (Churnside et al. 1995).

Direct measurements of the oceanic scattering and absorption parameters at a specific laser wavelength are difficult to obtain. Because light scattering and absorption are related to the intrinsic properties of pure water, and to the amount of dissolved organic and suspended particulate matter, measurements of these related parameters were obtained. CTD samples provided measurements of chlorophyll concentrations which are empirically related measures of light absorption due to phytoplankton and light scattering due to particulate concentrations. These measured parameters were used in developing a model of the lidar system's expected light propagation, and compared with results of measured values of propagation. The authors report that "the measured optical data were completely inconsistent with existing empirical lidar models, ... but the measured beam attenuation coefficients provided reasonable estimates of lidar attenuation and volume back scatter coefficients at a typical lidar wavelength". They attribute the inconsistencies with empirical models to the use of chlorophyll fluorescence as a measure of particulate density (Churnside et al. 1995).

The Kaman lidar was deployed in the rear of a Cessna 182 aircraft flown by a commercial fish spotter at altitudes between 800-1000 feet. Video images were collected during two days of flying on September 26-27, 1994 before a cooling pump failed. The system displayed a continuous image of an area approximately 50 by 75 feet at altitude. Subsurface objects appeared as either shadows or bright shapes depending on settings. Approximately 6 hours of video were collected, from which 16 images were digitally enhanced (Kaman 1995). The system detected an anchovy school at a depth of 55 feet, which was confirmed by sensors on the research vessel. Other images were obtained (although unsubstantiated) for tuna, manta ray, dolphins, and sunfish at depths of 10-30 feet (Kaman 1995).

At the request of Arete' Associates, we arranged for a number of U.S. Coast Guard flights, both before and during the research vessel cruise, and collected all data during these flights (Arete' 1995a). We also built and deployed four calibration targets consisting of 4 by 8 foot white sheets of 0.25-inch plastic suspended at various depths from floats (half of each target was painted a dull black). During data collection flights, we recorded video images, and other data, of subsurface objects at a variety of locations. These data are archived at the SWFSC. Images of the calibration targets and from a pair of common dolphins, *Delphinus delphis*, were extensively analyzed and subjected to the multispectral processing algorithms under development by Arete' Associates (Arete' 1995a). The authors reported that their processes reduced visible white water and other surface features while enhancing the subsurface features. They obtained peak and integrated video intensities as a function of calibration target depth for the test system, and model verifications on the effect of image blur due to light refraction by surface waves and in-water scattering.

Lidar Cruise II: 1995. Drs. Hunter and Churnside fielded a second lidar cruise aboard the David Starr Jordan during September 11-30, 1995 (Griffith 1995). During the week before the cruise, September 5-8, 1995, the extensively modified lidar system was mounted to a 30-meter deep tank at the Scripps Institution of Oceanography. The modified lidar system uses a frequency-doubled, Q-switched Nd:YAG laser, generating green light at a wavelength of 532 nm. Pulse energy varied between 50 and 100 mj with a pulse length of 10 to 20 ns. Expected depth penetration in local waters was to 10-30 meters. Live fish were maintained in the tank. An upward pointed underwater video system was placed at the bottom of the tank and connected to an external video display and recorder for continuous viewing. Another external video system was position at an observation port. During the week's trials, extensive testing and data collection were conducted to prepare the system for operation at sea and to obtain species-specific data on lidar back scatter from known live fish (Churnside 1996).

Following the deep tank tests, the lidar was moved to the *David Starr Jordan*. During the week of September 11-15, the system was operated in local waters during single day excursions. Extended sea tests began on September 16, 1995. The objectives of the ship tests were essentially the same as the previous cruise, although no calibration targets were deployed because the Kaman lidar was unavailable and the Arete' Associates project was not funded at the time. However, the area of operations was expanded and a greater emphasis was placed on repeated collections of lidar data on fish schools and the physical and optical properties of the ocean, especially near fronts.

Lidar measurements were taken continuously during the cruise, while the ship traversed a grid pattern designed to sample oceanographic fronts with differing water clarity. More than 280 hours of data were collected. The grid consisted of 25 stations, each approximately 5 miles apart. At each station, CTD data were collected to 200 meter depth. The CTD package also contained Niskin bottles to sample waters at various depths. Another package included an underwater radiometer measuring up-welled radiance and down-welled irradiance at 12 wavelengths (340-665 nm), a deck radiometer, two absorption and attenuation meters, transmissometer, Fluorometer, and a light scattering sensor. Sonar recordings were made continuously with the ships' depth finder and side-scanning equipment for comparison with the lidar data. Bongo tows were performed at four stations to collect samples of organic material. A high-speed trawl net was used to collect fish samples from schools after they had been passed over with the lidar beam. Operations were conducted during nighttime between September 24-29 (Griffith 1995).

This second lidar cruise was very successful. Lidar data were collected over a range of oceanographic conditions and on a variety of fish species. The results of analyzing these data will provide accurate estimates of the potential for lidar to detect fish schools, to identify fish species, and to develop as a survey tool. Extrapolation of the results to other water types will provide adequate estimates of the potential depth penetration and effective area of coverage for an airborne system designed to detect large yellowfin tuna in the ETP. Current plans are to install a lidar system in a twin-engine Partnavia aircraft in early 1997. We are exploring the availability of other sensors that could also be deployed from this aircraft. In conjunction with a number of research cruises, these sensors will gather data during aerial flights over the southern California Bight during the spring of 1997.

<u>ETP Seabird Research</u>. Because seabirds are commonly found in association with tuna and dolphins in the ETP (Au and Pitman 1986, 1988), and birds can be detected with S-band radar at distances of 10-15 miles, the Dolphin-Safe Research Program has included investigations of seabirds and seabird community characteristics in its investigations. Seabirds are important apex predators in the ETP ecosystem and have potential importance as indirect cues to the presence of large yellowfin tuna. Previous research has demonstrated that seabird flocks in the ETP are generally associated with only a few of the dolphin species common to the area (Au and Pitman 1986), and that these dolphin species are commonly associated with large yellowfin and to a lesser degree, skipjack tunas. Tuna fishermen have long taken advantage of the dolphin/tuna/bird association by visually locating birds and/or dolphins to capture the associated tunas (Perrin

1969).

Seabird investigations supported by the Dolphin-Safe Research Program have focused on the species composition of bird flocks associated with, and without, dolphins in the ETP and on the flight energetics and foraging ecology of predominant species in these flocks (Ballance 1993, Pitman and Ballance 1993, Ballance 1994a, 1994b, 1994c, 1994d, 1995a, 1995b, Au et al. (in press), Ballance (in prep), and Ballance et al. (in press)). Many seabirds commonly feed on prey forced to the surface by predators such as tunas and dolphins, although it is unclear if these feeding events are opportunistic or obligatory. If opportunistic, then the presence of a seabird species, or mixes of species, in an area might indicate the presence of a predator (e.g., tuna) but would provide little information on predator abundance or detection. If, however, the association of seabirds with predators is obligatory, then it may be possible to identify areas where tuna are more abundant through an analysis of seabird distribution and abundance. An obligatory association would also provide fisherman with a greater probability of capturing tuna because the association of seabirds and tuna would most likely be spatially strong.

Using a principal component's analysis for data collected over a ten year period (1979-1988), Ballance (1993) identified three "flock types" commonly associated with tuna/dolphin schools in the ETP. Each of the three "flock types" is a distinct, multi- species composition with a large proportion of one or two species: "Sooty Tern Flocks", "Juan-Wedge Flocks" comprised of Juan Fernandez Petrels and Wedge-tailed Shearwaters, and "Booby Flocks" comprised of both Red-footed and Masked Boobies. Ballance reported significant differences in flock size, species composition, body mass, and flock distribution in the ETP. "Booby Flocks" contained the highest average number of birds (48.9; s.e.=6.49), and occupied the eastern regions of the ETP. "Juan-Wedge Flocks" contained the fewest numbers of birds (25.3; s.e.=1.86) and occurred westward of the region occupied by "Booby Flocks". "Sooty Tern Flocks" averaged 32.6 (s.e.=1.22) birds per flock, occupied the western regions of the ETP, and were also found south of the equator. These reported distributions were found to be significantly correlated with the depth of the thermocline and surface-water chlorophyll content. In the ETP, productivity is higher in the East and lower in the West. Ballance (1993) suggested that the species composition of her "flock types" is affected by the existing geographical pattern of surface-water productivity in the ETP and by the energetic cost of locomotion for seabirds. Species with higher energetic requirements are limited to the more productive areas, while species with lower energetic requirements are able to utilize less productive areas.

Changes in the abundance and distribution of seabirds commonly associated with tuna schools could aid fisherman in locating productive fishing areas. Modifications to radars used to detect birds may be possible to optimize these devices for the species and body masses common to flocks associated with tuna schools.

<u>Proposal Database</u>**.** Since the inception of Tuna/Dolphin Research at the SWFSC (Perrin 1969), fishermen, scientists, and others have proposed methods to 1) reduce dolphin mortality in purse-seine fishing, 2) separate tuna from dolphins prior to capture, and 3) locate and capture

tuna not-associated with dolphins (NRC 1992). Much of the governmental effort during the seventies and eighties was directed at gear modifications and innovations to reduce dolphin mortalities associated with purse-seining (Coe et al., 1984; IATTC 1989). With the creation of the Dolphin-Safe Research Program at the SWFSC in 1992, our efforts have been directed at investigating tuna capture methods that do not involve encircling dolphins (DeMaster 1992).

Because the tuna/dolphin issue has been widely discussed for over 25 years, the Dolphin-Safe Research Program has received numerous proposals for research investigations from a variety of sources. We have actively solicited proposals through the Small Business Innovation Research Programs (SBIR), the Technology Reinvestment Project (TRP), the Saltonstall-Kennedy Grant Program (SK), and hosted workshops. Through discussions with fishermen, fish processors, fishing related industries, and other researchers, we have assisted with the development of research ideas. Lastly, because of the strong interest of the environmental community and media coverage, we also receive unsolicited proposals targeting dolphin-safe research investigations. Research proposals we have received range from simple statements about an idea to 100-plus page experimental designs. The proposals frequently contain proprietary data and information, and virtually all request some level of funding to accomplish the work.

As a means of organizing these proposals, we developed a "proposals database system". Each proposal is read and a briefing paper is developed describing the major thrust of the research, and a copy of the proposal filed for future access. In many cases, written or verbal contact follows receipt of the initial proposal. SBIR (Small Business Innovative Research, TRP (Technology Reinvestment Program), and SK (Saltonstall-Kennedy) proposals each have a formal review procedure which we facilitate through identification of potential reviewers. Table 1 shows the types of proposals we have received categorized by the method of tuna detection (direct or indirect) and technology (acoustical, optical, etc.). In the interest of furthering the development of dolphin-safe methods, and facilitating cooperative investigations between commercial enterprises and the fishing industries, we have included a list of proposal titles provided to the Dolphin-Safe Research Program since 1992 (Appendix 1). The address of the company and/or individual submitting the proposal is also listed. Further inquires about these proposals should be directed to the latter as we are unable to provide details on proprietary proposals.

External Funding Sources

Because funding was generally not sufficient to accomplish all of the identified research, we pursued outside funding sources external to our annual appropriation from Congress. These included the SBIR, TRP, and SK programs.

<u>SBIR (Small Business Innovation Research)</u>. The "Small Business Innovation Development Act of 1992" (15 U.S.C. 638, P.L. 97-219) required Commerce (and other agencies) to create "Small Business Innovation Research Programs (SBIR)" using a statutory percentage of their annual research and development budgets. Money from SBIR programs is awarded to small businesses

through a three-phase process, using contracts for the first two phases and non-government funding for the third phase. The program is not to be used as alternative funding for "current research activities", but rather as a means of obtaining "new ideas". Phase-1 proposals are targeted to demonstrate the feasibility of an idea, with the majority of the research and development leading to a product conducted during Phase-2.

Research topics are submitted to Commerce by Commerce organizations (generally NOAA or NIST) and an annual program solicitation is compiled and distributed around October (DOC 1993). Twenty-five page proposals are due at Commerce in January. Accepted proposals are then reviewed, rated, and ranked, with some number of Phase-1 contracts awarded around June. Commerce Phase-1 contract awards are limited to $50,000 with work to be performed during July-December. Phase-2 awards are limited to $200,000 with a longer period.

The October 1992, Commerce SBIR program solicitation identified 41 NOAA topics for which proposals could be submitted, including one submitted by the Dolphin-Safe Program: Topic 8.3.4, "Reducing Dolphin Bycatch in the Tuna Purse Seine Fishery". We received seven proposals (Appendix 1) for innovative research from this solicitation, obtained three critical reviews for each proposal, and submitted the reviews to Commerce. Competition for SBIR awards is intense, and although some of the proposals were highly ranked, none of the seven "dolphin-safe" submissions were awarded contracts during 1993.

We submitted a similar topic to Commerce in October 1993 and received six proposals from the solicitation during early 1994. A Phase-1 award was made to Arete' Associates entitled "Automated Airborne Tuna School Detector (Arete' 1993). A Phase-2 effort for the latter was not funded under the Commerce SBIR program during FY95, although we are attempting to further the development of the system. This joint effort is discussed below. Another group at the SWFSC submitted a similar topic for the FY94 solicitation: Topic 8.3.3, "Airborne Biomass Estimation of Fish Stocks", and received 8 proposals, some of which are related to our efforts. We again submitted a topic to Commerce in October 1995 (FY96) and received five proposals, none of which were funded.

Historically, Commerce has funded 5-10% of the Phase 1 proposals submitted. The FY 1996 solicitation indicated that DOC anticipated making about 45 Phase-1 awards (10 to NOAA and 35 to NIST). Only two Phase-1 awards were made for NMFS topics in FY96. Approximately one-third to one-half of the Phase-1 awards will subsequently receive Phase-2 awards, depending upon the availability of funds.

Although we have only had one proposal funded under the Commerce SBIR, the process of solicitation, submission, and review of proposals has provided many technical contacts and a wealth of information about potential solutions to finding alternatives to fishing on dolphins. The titles and contacts for past SBIR proposals we have received are included in Appendix 1. Requests for notification of future Commerce SBIR solicitations should be directed to:

DOC SBIR Program Manager
1315 East-West Highway
Room 15342
Silver Spring, MD 20910-3232
Tel: 301-713-4100

SBIR Award: Airborne Video System. Under a Phase-1, Department of Commerce Small Business Innovation Research (SBIR) contract ($50,000), Arete' Associates (Sherman Oaks, California), designed a passive, daytime, digital imaging system to detect, track, and assess dense schools of tuna in the ETP (Arete' 1995a, 1995b). The Automated Fish Finder (AFF) system incorporates a 3-chip CCD video camera, a fast (f/1.7) lens capable of providing a 50-degree field-of-view (FOV), computer, and proprietary software algorithms. The system displays either standard composite RGB video images, or images generated using Arete's multispectral and other filtering techniques for visual rejection of background (surface glare and whitecaps) and false detections (subsurface targets other than schools of tuna). The system is designed to be operated from either a fixed-wing aircraft or helicopter flying at an altitude of 2,000 feet. With a 50-degree FOV at 2,000 feet and a ground speed of 100 knots, the prototype system has an ocean image size of 1,700 feet by 1,300 feet, and an effective search rate of 200 km^2 per 2-hour flight. The AFF system is expected to detect dense schools of tuna to depths of 90 feet in the optically clear waters of the ETP.

Arete' Associates has developed techniques for optimal multispectral processing of the video RGB channels for coherent processing of images. In order to detect subsurface targets, it is first necessary to remove surface reflected light, and then use spatial matched filtering techniques to enhance the automatic detectabilty of targets. Multispectral processing involves capturing simultaneous images using the blue and red channels of the RGB 3-chip CCD. Because blue light penetrates ocean water deeper than red light, the "blue" image contains both the surface background information and signatures from below the surface. The "red" image contains only the surface background information. The two images are then aligned digitally and the "red" image subtracted from the "blue" image. The resulting image is a subsurface look into the depths with the surface clutter removed. Spatial filters can then be used automatically recognize targets of interest and to reject false targets.

During 1994, we collected ocean video data during a number of flights aboard U.S. Coast Guard helicopters based in San Diego, California. Targets consisted of 4x8 foot plastic sheets painted black and white and suspended at various depths, shallow water areas of sand and reef, dolphins at various depths, and small schools of coastal fishes. These data were collected using a hand-held Sony TR-101 High8 video camera, a super VHS recorder, and a Horita time code generator. Selected images were digitized by Arete Associates for analysis, as were photographic images of dolphins and tuna obtained from other sources. Additional efforts included performance tests on various video cameras, non-real time processing of digitized images, development and evaluation of computer algorithms to capture, register, and process images, and design of the prototype system.

Published measurements of fish reflectivities indicate fish have RGB color ratios different from background features (surface waves, glare, and glitter). Arete=s Phase-1 efforts validated this assumption. In addition, it was found that background features have a high level of coherence between colors. A sample composite RGB image of two near-surface, but submerged dolphins was digitized and processed using the techniques developed by Arete' Associates. In the RGB composite image, white-water created as the dolphins dove and wave features are evident in the image, but the dolphins signature is not particularly strong. The processed image shows reduced white-water and surface features, and significantly increased subsurface features (dolphins). A spatial matched filter corresponding in size to the dolphin-pair was applied to the color-differenced image and provided additional image enhancement. Arete' Associates calculated that in processed images of tuna schools at 90 feet, signatures may exhibit blur to about 1.5 meters. However, this degree of blur at maximum depth should not significantly reduce detectabilty of commercial quantities of dense tuna schools which are generally tens of meters in the horizontal aspect.

Included in the Phase-1 Arete' Associates final report were detailed design specifications for a real-time prototype system, field test plans, and performance testing to evaluate the system's capabilities. A proposal for SBIR Phase-2 funding was submitted in late 1994, but not funded by the Commerce SBIR Program. Arete' Associates is seeking interested parties to continue development of an Automated Fish Finder (Arete' 1995b), and can be contacted at the address below, or through the SWFSC' Dolphin-Safe Research Program.

Arete' Associates
Dr. Philip J. Davis
P.O. Box 6024
Sherman Oaks, California 91413
818-501-2880

TRP (Technology Reinvestment Program). Created as part of President Clinton's $20 billion, five-year Defense reinvestments and Conversion Initiative, TRP seeks to help defense companies find uses for their technologies in civilian markets. The Program involves the Departments of Defense (Advanced Research Projects Agency), Commerce's National Institute of Standards and Technology (Advanced Technology Program), Energy, and Transportation, as well as the National Science Foundation and the National Aeronautics and Space Administration. During 1993, the Program's solicitation received over 2,800 proposals valued at $8.5 billion and awarded approximately $472 million to 600 companies. Funding for the 1995 TRP was reduced in the spring of 1995 from $250,000,000 to $160,000,000 with approximately $10,000,000 available for SBIRs under TRP.

Within TRP, the Defense Department's SBIR program also involves a three-phase award system, but differs somewhat from the Commerce program. Under Defense SBIR, the solicitation is released in the April-May period with proposals due in July (ARPA 1993). Awards are generally made in January or February of the following year. Phase-1 awards are limited to $100,000 with Phase-2 awards not to exceed $375,000. Also with TRP, is the Commerce's Advanced Technology Program (ATP) which was funded at approximately $220,000,000 in FY96, although less than $25,000,000 was available for new projects.

After our first experience with the Commerce SBIR Program, and having reviewed a number of submitted proposals, we participated in the development of a TRP proposal for submission under the Defense Department's SBIR program during 1993. The proposal, "Long-Range Sonar Fish Detection: A Defense Conversion Opportunity for the Tuna Industry", was submitted (Scientific Fishery Systems 1993) as a Technology Development Activity under the section Environment Technology: Environmental Monitors in (ARPA 1993). Unfortunately, the proposal related to our efforts was not one of the approximately 71 Phase-1 proposals selected for award. Requests for notification of future Defense SBIR and Commerce Advanced Technology Program solicitations should be directed to the appropriate address listed below.

Advanced Research Projects Agency (ARPA)
ATTN: OASB/DTCC/SBIR
3701 N. Fairfax Drive
Arlington, Virginia 22203-1714

US Department of Commerce
National Institute of Standards and Technology
Advanced Technology Program
Bldg. 101, Rm. A430
Quince Orchard and Clopper Roads
Gaithersburg, MD 20899-001
tele: 1-800-ATP-FUND Internet: http://www.atp.nist.gov

SK (Saltonstall-Kennedy). The Saltonstall-Kennedy (S-K) Act, as amended (15 U.S.C. 713c-3), established funding for fishery's research and development project grants. The Secretary of Commerce makes appropriated funds available for grants to address aspects of U.S. commercial and recreational fisheries. NMFS issues notices of fund availability, provides application packages describing grant application submission, and administers the application and award process each year. Application packages can be obtained from a number of NMFS Regional Offices. Further information on the program and the addresses of Regional offices can be obtained by contacting:

S-K Program
Office of Trade and Industry Services
National Marine Fisheries
1315 East-West Highway
Silver Springs, Maryland 20910

(301) 713-2358

Grant applications for 1996 were due at NMFS Regional Offices by May 20, 1996. This year's program provides for $7,000,000 in grant funds. Funding priorities were developed in consideration of the NOAA Strategic Plan which includes a focus on rebuilding U.S. fisheries for sustainable use. Three of the five funding priorities (bycatch, fisheries utilization, and fisheries management) are directly related to the goals of the Dolphin-Safe Program, and we provided information to a number of groups that have submitted grant applications.

Research Planning Workshop II

The Second Dolphin-Safe Research Planning Workshop was held at the SWFSC on March 14-17, 1994 (Edwards et al., 1995). Planning the workshop began in 1993 (PO 40JGNF0139; $9,800) and continued in 1994 (PO NFFR2100300041; $15,000). Reports on the planning activities and an evaluation of the workshop are in Starfield and Ralls (1993, 1994). The workshop focused on dolphin-safe methods of detecting and capturing large yellowfin tuna in the ETP. Dolphin-safe methods are defined as those which do not involve intentional encirclement of dolphins. The workshop's primary objective was development of a research plan to guide activities within NMFS' Dolphin-Safe Research Program during the next 3-5 years, with emphasis on commercially promising detection methods. Workshop participants included technical experts familiar with various detection and capture methods, fishing experts familiar with the ETP tuna purse-seine fishery, and government agency scientists involved in the tuna- dolphin issue including representatives from the U.S. National Marine Fisheries Service, Mexico's Programa Nacional para el Aprovechamiento del Atun y Proteccion de los Delfines, and the InterAmerican Tropical Tuna Commission.

Workshop participants were specifically instructed to limit discussions 1) to large yellowfin, 2) to the ETP, 3) to detection methods other than dolphin cues, and 4) to capture methods that do not involve encirclement of dolphins. The specific topics chosen for discussion and evaluation at the workshop included acoustic, optic, and radar/SAR detection methods and pair trawling.

<u>Acoustic Detection Methods</u>. The technical experts unanimously recommended two preliminary modeling projects: 1) modeling of acoustic signal propagation within and below the shallow mixed layer of the ETP to provide preliminary estimates for design parameters (ranges, power, resolution, etc.), and 2) determination of acoustic target signatures of large yellowfin tuna to compare with design parameters. Experts were emphatic that these studies be completed prior to <u>in</u> <u>situ</u> testing or actual system development. Further research into acoustic methods will depend upon the results achieved during these two fundamental projects.

Results from both the signal propagation and target strength modeling projects will provide a basis for determining which acoustic detection methods have the greatest commercial potential for detecting large yellowfin tuna in the ETP environment. The modeling studies will be designed to provide predictions of performance (including minimum and maximum ranges, and associated resolutions) for various system designs and costs, using a range of parameters specific to the ETP tuna fishery.

Optical Detection Methods. Before attempting to design an optical detection system, optical characteristics of both the ETP system and the desired target need to be defined. Based on these preliminary efforts, decisions can be made about the appropriate direction(s) for system development. The optical properties of large yellowfin tuna, which need to be determined in order to design an optical system optimized for detection of these particular targets in the ETP, can be derived from specimens. Technical experts unanimously recommended preliminary modeling studies to predict performance of existing and proposed systems, and to provide estimates of range and cost for systems predicted to perform well in the ETP.

Of the proposals received by the Dolphin-Safe Program, technical experts selected for further discussion only Lidar (LIght Detection And Ranging) for active methods, and high-sensitivity video for passive methods, as practical optical systems for current or near future application in the ETP fishery. Other systems, while perhaps promising, were not considered to be as close to practical development and application.

Lidar systems direct a generated light source into the water and receive back reflected light from underwater objects. Using narrow band lasers and filtered photodetectors, lidar systems should be able to detect objects at depths 3-6 times greater than the unaided human eye (e.g., 30-60 meters).

High-sensitivity video was the passive optical system of choice because it appears to be readily attainable and relatively inexpensive. It would be effective primarily during daylight and even then only during periods of high solar elevation, but such a system could potentially increase imaging depth from about 10 meters using the human eye and polarizing lens, to 10-20 meters with a video camera using a polarizing lens. With additional signal processing, a video system could probably detect images as deep as 30 meters and possibly as deep as 40 meters under ideal conditions. Such a system could potentially double or triple whatever volume of water is now observable with human eyes and reduce or eliminate many of the problems associated with the frailties of human vision (e.g., distractions, fatigue, glare, etc.).

Radar Detection Methods. Signal propagation and target signatures need investigation prior to redesigning a radar system for ETP tuna purse-seiners. Radar target characteristics of surface disturbances caused by individual tuna and tuna schools, birds, and floating objects need to be identified so that required power, sensitivity, and associated design criteria (e.g., antenna size) can be estimated. A useful related study would investigate constraints associated with designing a helicopter-based radar (in particular, an improved S-band bird radar).

Pair Trawling. A preliminary study not addressed by workshop participants, but certainly necessary before the US government commits significant effort in ETP pair trawl development, would be a thorough evaluation of the ecological and economic consequences of introducing this new type of gear to the already established purse-seine fishery in the ETP, including consideration of pair trawling's likely effect on the other fishing modes (school and log fishing) in addition to dolphin fishing. Past problems with fishery interactions and over-capitalization in other areas, and bycatch problems both in the ETP and elsewhere would need to be carefully addressed prior to U.S. government involvement in initiating a new fishery in the area.

<u>ETP Tuna Survey</u>. A relatively comprehensive picture of the possibilities for locating and capturing large yellowfin tuna in the ETP emerged from the extensive discussions during the workshop. In general, success of any capture process will be affected by three or four distinct aspects of the process; distribution of the fish (horizontally and vertically), detection method, separation method (if necessary) and capture method.

Distribution is important because the most effective method(s) to detect, separate if necessary, and capture large yellowfin tuna in the ETP will depend upon whether the fish are scattered, schooled, or associated with either dolphins or floating objects, and whether the fish are near surface or at depth. If the fish are near surface and cause identifiable surface disturbances, SAR imaging may be appropriate. If the fish are near surface but not causing identifiable surface disturbances, optical detection (especially some form of Lidar) is likely to be effective. If the fish are attracting birds, enhanced bird radar is likely to be useful. For fish within 5 meters of the surface, any of the optical or radar/SAR methods are likely to be as effective or possibly more effective than acoustical methods, which may have problems detecting near-surface fish due to acoustic interference associated with the air-water interface.

If fish are near-surface but too deep to produce a surface effect, SAR/radar will not be effective. Optical and acoustical methods will likely be most effective for these depths (5-50 meters).

If the fish are deeper than about 50-75 meters then optical detection methods are unlikely to be effective but acoustical methods still hold great promise. In fact, acoustical detection is the most promising method overall because acoustical detection range will far exceed optical detection range underwater under almost all circumstances (radar and SAR can only detect surface or airborne phenomena). The volume of water sampled by relatively long-range acoustical devices will be much greater than the volume accessible to optical search, therefore the probability of acoustical detection will be much higher. Optical systems will likely outperform acoustical systems only in short- range applications and only if water clarity is high. Under these conditions, a helicopter-mounted optical system may be able to search a larger area and greater volume than would be possible with a short-range acoustical system.

Fish distribution also affects the type of capture method most likely to be effective. For schooled or associated fish, either purse-seines or trawls will be effective. For scattered fish, trawls have promise but purse-seines would be ineffective. For dolphin-associated fish, separation prior to capture is necessary for the captured fish to be considered "dolphin safe". Two potential avenues exist for separation; mechanical and behavioral (subsuming here, avoidance or attraction behaviors related to chemistry). Pair trawling is a promising method of mechanical separation although ecological and economic consequences of introducing this gear need to be addressed prior to committing resources to its development. Other mechanical or behavioral methods have been proposed but preliminary tests, where they exist, have not been promising.

Whether capture is worth pursuing once the fish are detected then depends upon whether there are commercially exploitable numbers of them. Provided the acoustical models are promising, acoustical modeling and validation studies should be followed immediately by planning and deployment of an acoustic survey to determine distribution and abundance of large non-associated yellowfin tuna in order to assess whether fishable quantities exist in the ETP. Such a survey will have to be acoustics-based as only acoustics will be appropriate for a wide-area, subsurface survey. If results from both the validation experiments and the acoustical survey are promising, then resources should begin to flow into system development for a commercially available acoustic detection system at a reasonably accessible price.

Detection Technology Investigations

During 1995, NMFS funded two acoustic modeling projects and a third project to investigate potential enhancements to radars to locate tuna. No optics modeling projects were initiated because of reduced funding levels. Reports were obtained for each of the three projects and a synopsis of results and recommendations follows.

<u>Acoustic Target Strength of Yellowfin Tuna Schools</u>. Funds ($6,000; 40ABNF501351) were provided to the Naval Research Laboratory, Center for Environmental Acoustics, Stennis Space Center, Mississippi to use acoustic scattering models of fish schools to predict scattering from large yellowfin tuna at frequencies of 50 Hz to 200 kHz (Nero 1996). We provided tuna life history parameters and tuna school characteristics for use in computer simulations of expected acoustic target strengths for schools of tuna. Although not possessed by all tunas, large yellowfin and bigeye tuna do have a swimbladder. Gas-filled volumes such as swimbladders provide the strongest return signal from an active acoustic signal at the resonance frequency for the volume. The purpose of the modeling simulation was to ascertain both the optimum detection frequency and the expected target strengths of schools of tuna.

The two scattering models used required some knowledge of the characteristics of both individual tuna and a tuna school: a low frequency, near swimbladder resonance model (Feuillade et al. 1996) and a high frequency model for frequencies well above swimbladder resonance (Love 1981). Both models calculate target strengths for tuna schools insonified at horizontal aspect. Because we are interested in detecting commercial quantities of large yellowfin tuna that are near enough to the surface to be captured, the parameters used in these simulations may not apply to other fisheries.

Dolphin-associated tuna schools are generally composed of the most dis-similar size fish (schoolfish are less variant, and logfish the least variant in lengths). We specified an average tuna school weighing 16.5 tons with a 20 % standard deviation about length to create a random length distribution. The "average" yellowfin tuna caught in the ETP weighs 25 pounds. Dolphin-associated yellowfin tuna range from 25-100 pounds (80- 130 cm). Computer simulations were executed for the following fish lengths and number of fish in a "school".

23 pound fish (80 cm);	1448 fish/school
45 pound fish (100 cm);	738 fish/school
60 pound fish (110 cm);	554 fish/school
100 pound fish (130 cm);	334 fish/school

We were unable to locate any references pertaining to recent studies on gas bladders in larger yellowfin tuna (>80cm). The literature has a few references to gas bladder lengths and shapes for yellowfin tuna in the 120-140 cm range, but nothing on the gas bladder volume for these larger tuna. The data presented in Magnuson (1973) is derived from yellowfin tuna less than 10kg (~80cm). Magnuson (1973, 1978) showed the gas bladder allometrically increases with body length (mass); fish weight increases approximately as a cubic function of length and therefore 1) gas bladder volume must increase to reduce density, or 2) fat content must increase to decrease density, or 3) fish must swim faster to increase lift, or 4) lift must increase (bigger pectorals), or 5) some combination of these and other factors. We specified swimbladder volume as a percentage of fish volume, which was reported by Magnuson (1973) to be equal to 0.054 times Body Volume (e.g., Mass).

Yellowfin tuna apparently spend very little time at the surface. Much of what we have read indicates daytime orientation to depths associated with the top of the thermocline and lower mixed layer. From these depths, yellowfin tuna appear to make frequent, abrupt vertical excursions into the mixed layer, and occasionally to the surface. At night, yellowfin appear to orient much shallower but not at the surface. In the ETP, the thermocline is relatively shallow (40-150 meters) with lower mixed depths commonly 30-50 meters (deepens from East-to-West). We specified the tuna school depths of 10, 30, 75, and 100 meters.

We specified that yellowfin tuna schools were discoid (length=width) in shape, but were uncertain about the depth aspect of schools in relation to length and width. We suggested computer simulations be performed using vertical/horizontal aspect ratios of 1/10 and 1/5.

We interpreted the data reported on the visual acuity of yellowfin to suggest a maximum separation distance of 10 Body Lengths for a "traveling" school in the "20-meter; Type I" water common to the offshore ETP. Minimum separation distance appears to be 0.5 to 1.0 Body Lengths. We specified packing densities for tuna schools using 1, 3, 7, and 10 Body Lengths separations.

Results. Nero (1996) identified several tuna school parameters that affect the choice of frequency and bandwidth for an active acoustic detection system. Number of fish, fish spacing, and depth affect school target strength at low frequencies (50 to 1000 Hz) due to coupled resonance and coherent interference. School target strengths for 80-130 cm fish numbering 300-1400 individuals was highly variable, ranging from 2 to 18 dB at resonance frequency. Above and below resonance, target strength variations ranged as high as 40 dB. At high frequencies (2 kHz to 200 kHz) school target strength ranged from 0.9 to 2.5 dB, and was primarily affected by the number of fish and fish size, with little effect associated with fish spacing and depth. Nero (1996) recommended use of broadband acoustic systems at either low or high frequency in order to detect tuna and to discriminate tuna from other fish which might also be resonant at the frequency chosen.

A number of research recommendations were also identified in Nero (1996) to both validate the models used and to provide data to more precisely identify an optimum frequency and bandwidth for the acoustic detection of yellowfin tuna. Direct measurements of the swimbladder and buoyancy characteristics of large tuna (80- 130 cm) and both low and high frequency target strengths from live tuna schools are desired.

Acoustic Detection of Tuna Schools in the ETP. Funds ($43,000 40ABNF501351) were provided to the Naval Command, Control, and Ocean Surveillance Center (NCCOSC), San Diego, California, to assess the impact of acoustic propagation on the feasibility of long-range acoustic detection of yellowfin tuna schools in the eastern tropical Pacific Ocean (Rees 1996).

Acoustic detection of yellowfin tuna can be either passive by detecting the sounds that tuna make, or active by detecting acoustic energy reflected by a fish school that has been insonified by a sound source of known frequency and bandwidth. As described in Rees (1996), the important questions to answer in assessing the feasibility of acoustically detecting fish schools are: 1) what is the transmission loss of the emitted, or reflected, sound source as it propagates through the medium?, 2) what is the target strength emitted, or reflected, by a school of tuna?, 3) how much noise is present at the receiver to interfere with detection of the emitted, or reflected, signal from the tuna school?, and 4) how efficient if the receiver?

Sixteen sets of characteristic acoustic propagation conditions were developed for an area of the ETP between 0-20 degrees North latitude and from the Central America coast to 140 degrees West longitude. Typical propagation conditions were derived using average ocean climatic conditions in the area. Tuna school target strengths were obtained from a separate modeling study (Nero 1996). Two range regimes were addressed (medium-range 2-40 km and long-range 40-200 km) for three depths (50, 100, and 200 m), using an active omnidirectional source. The source was assumed to be positioned at a depth of 20 meters co-located with the fishing vessel and with the receiver array roughly co-located with the source. Various ocean volumes were analyzed for frequencies between 200 Hz and 20 kHz. Acoustic transmission losses, tuna school target strengths, and required source levels were modeled to obtain specified probabilities of detecting a tuna school using characteristic propagation conditions, assumed receiver configurations, and tuna school characteristics.

Results. The report by Rees (1996) indicates that for a distant-range volume (40-200 km), detection of schools of yellowfin tuna is feasible in the ETP using source levels that are louder than currently available from commercial sources (above 180 dB), but within the range of US Navy acoustics sources. For a medium-range volume (2-40 km), detection is feasible using easily constructed systems with much lower source levels (below 180 dB), assuming receiver noise can be adequately suppressed. However, even if receiver noise is high and the modeled systems less effective, they would still have better operational detection than currently available high frequency systems.

Although lower source levels yield reduced detection distances in the above configuration, possible techniques to lower required source levels and/or extend the detection distance include 1)positioning source/receiver at optimized depths, 2) positioning receiver in low boat-noise area, 3) using directional source instead of omnidirectional source, 4) incorporating advanced signal processing methods, and 5) incorporating frequency signature processing optimized for tuna schools.

Given the need to suppress receiver noise, Rees (1996) recommends a pulsed, near 5-kHz source (preferably directional), with maximum commercial strength. A matched towed-array receiver system, positioned in a low boat-noise region, would use conventional directional processing techniques with time-gating keyed to the source. Such a system would maximize the probability of detecting a tuna school at any distance. Construction and operation of a simple prototype system aboard a tuna vessel would provide needed information of the ability to suppress receiver noise and the response of yellowfin tuna (and nearby dolphins) to the insonification signal at the required source levels.

Radar Enhancements

Funds ($25,000 40ABNF501351) were provided to the Naval Command, Control, and Ocean Surveillance Center (NCCOSC), San Diego, California, to study how tuna vessel radars might be optimized and used to improve the detection of yellowfin tuna schools in the eastern tropical Pacific Ocean (Summers 1996). Emphasis was placed on cost effective enhancements that would extend the range at which bird flocks (often associated with tuna) could be detected, and the feasibility of detecting "breezers" (free-swimming tuna schools) and "logs" (often associated with tuna).

A detailed computer model was developed that allowed prediction of radar performance as a function of radar parameters, propagation conditions, and bird flock composition common to the ETP tuna fishery. Both S-band and X-band radars are common on tuna vessels with the former used to detect bird flocks. Interviews with tuna boat captains indicate that S-band radars are capable of detecting bird flocks at heights of a few hundred feet altitude, at distances up to 10 miles, and even a single frigate bird, *Fregata fregata*, flying at a height of 1,000 feet, at distances of 10-15 miles. The computer model developed in this study confirms that such performance is possible.

Results. Using an analysis of bird flock composition (Ballance 1993), a published reference on the body masses of birds (Dunning 1993), and an unpublished report providing a reasonable approximation of average bird cross section as a function of bird mass (Vaughn circa 1985), Summers (1996) concluded that the simplest approach to increase the detection distance of bird flocks would involve increasing the vertical dimension of the radar antenna. Increasing the vertical size of an antenna from 6.9 to 28 inches should increase gain from 27 dB to 33 dB. Such a gain increase should increase the median bird flock detection distance by about 50% (14.4 miles versus 10 miles) for an S-band radar mounted at a height of 85 feet. Similarly, the computer model predicts that a single frigate bird flying at 1,000 feet would be detected at a distance of 20 miles (versus 10 miles) using the larger antenna.

Summers (1996) reported that accurate detection of tuna schools Abreezing@ near the surface is not currently possible because there are few data on either the sea-surface radar cross-section return created by a tuna school or the backscatter return due to wind. X-band radars could be modified to obtain longer measurements of average sea backscatter, from which significant variation could indicate the presence of a fish school. Assuming the cross-sectional backscatter resulting from a fish school is the same as that resulting from a narrow range of wind speeds, and fairly constant winds while fishing, then a significant change in perceived wind speed (as measured by the radar return) could be used to indicate a fish school. However, small changes in backscatter should only be discernible under low sea conditions (light winds and small seas). Maximum detection distances are predicted to be 1-2 miles for "effective wind" changes of less than 4 kts with maximum winds of 8 kts. At higher wind speeds, the sea return will likely mask any effect due to fish schools unless the radar return from the fish school is large.

Summers (1996) reported that the detection of logs is likely to be constrained by the same parameters associated with detecting breezers. There are no documented measurements, nor means for estimating, radar cross-sectional returns from logs.

Summers (1996) suggests that proper training in the use and care of radar can help fishermen maximize the radar's performance. The higher a radar antenna is mounted and the higher the average power and antenna gain, the better the system will perform. Although automatic detection of "bird trails" in the noise clutter displayed on the radar screen is possible, he believes a properly trained fishermen will perform better than a novice under most circumstances. Fishermen should be aware that propagation ducting will cause considerable performance variations, which cannot be predicted, but will be evidenced by their effects on the radar. In particular, bird trails may appear to be one, two, or three range intervals closer than the real location of the bird flock when propagation ducting occurs. Thus, fishermen may want to further investigate apparent targets at locations beyond where they appear.

Lyne et al. (1992) used a small, lightweight X-band side-looking airborne radar (SLAR) mounted in an aircraft to detect schools of jack mackerel at distances up to 30 km. Target observations were made from altitudes of 350-650 m and ground speeds of 130-160 knots. Radar detection at these distances was possible because of the large radar return resulting from the surface disturbance created by frenzied feeding schools and image enhancements produced by an onboard technician. Non-feeding schools of southern bluefin tuna and skipjack tuna were observed to create a surface rippling effect similar to that produced by light winds, but the radar return from these targets was weak. They also report that their SLAR system was able to detect tuna schools in the Seychelles at ranges exceeding 35 km with wind speeds to 20 kts, but do not provide any information on the behavior of these latter fish schools.

Radar detection of fish schools is possible only when there is a significant difference between the radar backscatter created by the surface effect from the fish school and that resulting from wind and seas. The frequency at which fish schools create sufficient surface effect to overcome ambient backscatter is unknown, but does occur. Summers (1996) indicates that data on the radar signature from tuna schools is needed, but that expected detection ranges with X-band radar aboard tuna vessels will probably not exceed 5 miles because of the generally large ambient backscatter from wind and seas. By raising the "look- angle" of a radar and performing computer enhancements of images, Lyne et al. (1992) greatly increased the distance at which the surface-effect created by fish schools could be detected. This is primarily a result of a reduction in the total backscatter from wind and seas. The authors suggest that use of a longer- wavelength radar (L-band) may be better suited for tuna schools when they create subtle effects (e.g., rippling waves) at the surface.

Separation/Attraction Workshop

A workshop was held at the Southwest Fisheries Science Center on September 20, 1995, to evaluate the potential for separating tunas and dolphins prior to capture by purse-seine. The workshop was attended by scientists and tuna skippers long familiar with the tuna-dolphin association. Workshop participants were not encouraging about the practical nature of most proposed research in this area, based on experience and results of earlier research attempts.

A workshop report (Edwards, in prep) summarizes the practical constraints that must be accounted for in any future proposals for investigation into this area. A review of prior research in this area and results of workshop deliberations are included in the report.

Fishery-Induced Stress in ETP Dolphins

A recently completed study in the Dolphin-Safe Research Program involved analysis of color darkness in adrenal glands as an indicator of stress in dolphins captured by purse-seines in the ETP (Myrick and Perkins, 1996). This study was subsequently review by five highly qualified wildlife physiologists, two specializing in terrestrial wildlife and the other three specializing in marine mammals. All five reviewers offered suggestions for significant improvements to be incorporated into any future studies of fishery-induced stress. Currently available data show no strong evidence of any stress effects.

Other ongoing or proposed dolphin stress projects are summarized in Myrick (1995). Related studies investigating potential capture rates of ETP dolphin schools as a function of school size will appear in Perkins and Edwards (in prep.) and Perkins and Gerrodette (in prep.).

ETP Tuna Bycatch Study

Each of the three fishing modes of purse-seining for tuna in the ETP (log fishing, school fishing, and dolphin fishing) generates bycatch (catch of non-target animals). Bycatch from dolphin sets is primarily dolphins; few other animals are caught in these sets other than the dolphins and associated yellowfin tuna. Bycatch from log and school sets includes significant amounts of tuna, including small individuals of the target species, yellowfin tuna. The extent of tuna bycatch from all three types of sets was estimated from data collected by scientific observers on US boats during the years 1989-1992. Development of estimation procedures and preliminary results have been published by Perkins and Edwards (1996).

The estimation methods described in Edwards and Perkins were then applied and extended to a estimate of tuna bycatch from all three set types, for both the US and the international fleet during 1989-1992. The results from this latter analysis appear in Edwards and Perkins (in review). The report's abstract provides the following summary.

Expected tuna discard per set was 100 times higher for log sets, and 10 times higher for school sets, than for dolphin sets. Expected tuna discard per set varied significantly between three geographic areas for log and school sets but was relatively constant fishery-wide for dolphin sets. Average expected tuna discard per set for log sets was 10.5 tons (s.e.=0.83, n=998, range 7.1-15.4 depending on geographic area, with greater bycatch occurring inshore along the coast of Central America), for school fish sets was 1.15 tons (s.e.=0.24, n=960, range 0.97-1.57 depending on geographic area, again with greater bycatch occurring inshore along the coast of Central America), and for dolphin sets was 0.06 tons (s.e.=0.2, n=2110, with no significant difference between geographic ranges (i.e., fishery wide).

Estimated average annual tuna discard by the U.S. fleet during the study period was 5,400 (s.e.=426) tons per year due to log sets, 595 (s.e.=125) tons per year due to schoolfish sets, and 88 (s.e.= 29) tons per year due to dolphin sets. Hypothetical redistribution of all dolphin sets to school sets during the study period increased estimated average annual tuna discard from school sets from 595 to 2,180 short tons and increased the estimated U.S. fleet total discard from 6,080 to 7,580 short tons (+25%). Hypothetical redistribution of all dolphin sets to log sets increased estimated annual discard from log sets 3.7 times, from 5,400 to 19,900 short tons and increased the estimated U.S. fleet total 3.4 times, from 6,080 to 20,500 short tons.

Redistribution calculations are important because the international fleet is under pressure to cease fishing on dolphins. Average annual discard of tunas by the international fleet in the ETP (of which the U.S. was only a small part) increased from an estimated 31,500 short tons under observed effort patterns to 106,000 short tons per year after hypothetically redirecting all dolphin sets to log sets.

Although yellowfin tuna comprise only about 22% of the tuna bycatch from log sets, about 76% of these yellowfin are small, pre-reproductive fish. Redistributing all dolphin effort to log effort increased estimated discards of small yellowfin to 10-25% of the estimated average number of recruits to the fishery each year. This loss to discards would occur in addition to an estimated 25% reduction in catch biomass (reported in a study by other researchers) expected to occur simply due to changes in size structure of the landed fish. These combined effects could lead to potential removal from the stock of 35-50% of recruitment annually. Even absent a stock recruitment relationship, sustained removals of this magnitude, combined with environmental variability, could pose problems for long-term sustainability of the resource.

Tuna fishermen are opportunistic and generally set their nets on dolphins, logs, or schoolfish as they find them. There are temporal and spatial distributions between these three types of tuna fishing (Greenblatt 1979, IATTC 1992, Punsly and Mullen 1994). Log fishing tends to be concentrated in the more coastal waters where rivers discharge logs and other debris into the sea during the rainy season (Greenblatt 1979). It is unknown if there are sufficient numbers of Aexcess@ logs in the ETP to support increased effort by tuna fishermen forced to fish Adolphin-safe@. It is also unknown at what rate logs that are fished upon are replenished with tuna schools. Similar arguments exist pertaining to the schoolfishing method of tuna fishing. Thus, a potential alternative effect from Adolphin-safe@ fishing methods could be reduced tuna catches without an increase in the bycatch of non-target species, because fewer sets could occur. It may be possible to modify gear and fishing procedures to mitigate bycatch mortality of non-target species, as has been demonstrated with dolphin mortalities.

Non-ETP Dolphin-Fishery Interactions Review

The prominence of the tuna-dolphin fishery in the eastern tropical Pacific Ocean (ETP), and the expansion of tuna purse-seine fisheries to many ocean areas outside the ETP has led to repeated speculations about the potential for significant purse-seine fishery-related dolphin mortalities occurring in areas outside the ETP. In order to investigate this possibility, all available literature containing references to interactions between dolphins and purse-seines outside the ETP were reviewed in an annotated bibliography.

The available literature contains a very incomplete picture of the situation world-wide.

There are a few reports of fishing Aon dolphin@ similar to the procedure in the ETP, and these reports tend to indicate very limited dolphin mortalities. In general, existing data suggests that little dolphin fishing and very few dolphin mortalities occurs outside the ETP.

However, these data were collected during only a very small fraction of the total effort expended on tuna purse-seining in areas outside the ETP. While the geographic coverage overall seems to be reasonably complete (i.e., reports exist from at least portions of all the major tuna purse-seine fisheries in the western Pacific Ocean, eastern Atlantic Ocean, Indian Ocean, and Mediterranean Ocean), very few data have been collected from any one area. The existing data do indicate that the potential for interactions between dolphins and tuna purse-seine fisheries may be greater in some areas than others (e.g., off the coast of west Africa near the Cape Palmas area, and around the Seychelles and Sri Lanka in the Indian Ocean). While it cannot be determined at present whether these areas actually experience greater numbers of interactions, or simply represent the areas where purse-seine vessels make port in the greatest numbers, the assured lack of sufficient funds to fully investigate all potential fisheries suggests that these areas of apparent activity might be best investigated first.

Dolphin School Capture Rate Study

The possibility of fishery-induced stress effects on dolphin physiology, behavior, and population dynamics (reproduction, survival) has been suggested repeatedly since the inception of the purse-seine fishery in the early 1960's but there is little quantitative evidence either for or against such effects. One of the major determinants of the amount of stress incurred will be the number of times the stressor occurs for individual dolphins.

While the number of times a particular individual has been captured and released cannot be estimated directly from data currently available, it is possible to estimate the frequency with which dolphin schools of a given size are set upon. This has been done for northeastern spotted dolphins (comprising over 80% of the sets made on ETP dolphins) by comparing the number of schools of various sizes actually present in the stock, to the number times schools of various sizes are set upon by tuna purse-seiners. Set frequency for individual dolphins can then be roughly Abracketed@ by making assumptions about the fidelity of individual dolphins to individual schools, ranging from complete fidelity to complete fluidity (infidelity) between schools.

The study shows a very strong selection by tuna purse-seiners for larger schools and avoidance of smaller schools, such that schools of over 1,000 animals may be set upon as much as once a week, while schools of less than 100 appear to be set upon only once or twice a year. Because over 50% of the individual dolphins appear to occur in schools of less than 100 animals, while only about 10% of dolphins appear to occur in schools larger than 1,000 animals, it seems likely that only a relatively small fraction of the total stock are subjected to capture stress with any significant frequency. The range of potential capture frequencies for individual dolphins has not yet been estimated, but will appear in the final report (Perkins and Edwards, in prep.).

Proposed Future Research

Future research will obviously depend upon funding, but the need for continued work in three general areas is clear.

I) Continued investigation of detection technologies, including:

1) completing the evaluation of potential for acoustic detection of unassociated large yellowfin tuna in the ETP, i.e., design and testing of a optimized system for locating the fish, and survey to determine distribution, abundance, and ultimately, potential for commercial success in fishing for unassociated large yellowfin tuna in the ETP.
2) completing examination of swimbladder characteristics of large yellowfin tuna, for refining acoustic target signature definition.
3) completing the evaluation of potential for optical (lidar and/or enhanced video) detection of unassociated large yellowfin tuna in the ETP. Because optical detection methods will always be useful only in a local sense, no survey is planned using this type of technology.
4) investigating the possibility that radar manufacturers might develop the larger bird radars recommended by the contract report on radar detection potential.
5) investigating the potential for FADs as concentrating mechanisms for capturing large yellowfin tuna in the ETP, including focus on evaluating and reducing non-target bycatch.

II) Evaluation of the potential for detrimental effects on ETP dolphins from proposed tuna detection technologies:

1) evaluate potential for acoustic damage and/or disturbance
2) evaluate potential for optical damage and/or disturbance

III) Contingent upon passage of pending legislation to resume dolphin fishing by U.S. vessels (and lift the embargo against tuna caught Aon dolphins@ by non-US nations), resumption of research focus on dolphins, including:

1) renewed estimation of abundance and trends in abundance
2) initiation of studies to evaluate effects of fishery-induced stress ETP dolphin stocks.

Additional detail concerning areas I) and II) appear below. Activities under III must await resolution of pending legislative changes.

Acoustic Detection Systems

Active Detection Systems: The highest priority future project is design, construction, and field testing of a low-frequency, tuna acoustic detection system based upon the previous work by Nero (1996) and Rees (1996). These reports considered a number of scenarios, categorized the ETP fishery in terms of ocean environment, and derived general results and constraints that would apply to any tuna acoustic detection system operating in the ETP. The Rees (1996) and Nero (1996) reports indicate that a high-source level, low-frequency acoustic system should be able to detect yellowfin tuna at distances up to 200 km. Lower source levels yield reduced detection distances. Rees (1996) recommends a practical system to detect schools of tuna at distances between 2-40 km and to depths of 100 meters. Such a system would be a vast improvement over current sonars which have ranges of only 2-4 km. Development of a new optimized design is currently underway. Construction could begin during the second half of 1997, and field tests could occur in 1998, subject to funding levels. NOAA research vessels and possibly Scripps Institution of Oceanography vessels, would be used for the early tests in the either the ETP or Hawaiian Islands area.

This effort will expand on acoustic propagation and detection modeling previously done at NRaD for the Dolphin-Safe Research Program, to develop an optimized environmental design for an active acoustic tuna detection system. By "optimized" it is meant that the study will identify the leading candidates for: source type, source directionality, operating source level, length of towed-array receiver, number of elements in receiver, operating depth of receiver, and various other parameters as conditioned by the expected ocean environmental conditions in the Eastern Tropical Pacific fishing area.

General transmission loss (TL) and probability of detection (PD) values have already been obtained for characteristic ETP conditions. This study would use the same modeling techniques applied in the previous study but focus on the previously identified optimal frequency regime and, by considering propagation loss, target strength, boat noise fields, and other parameters, identify a specific source/receiver configuration that would be optimal for an acoustic tuna detection system operating in the ETP. The report would discuss how changes in the ocean environment would change the optimal design. The report will identify specific optimal values for general ETP ocean conditions including:

- source type
- source directionality
- operating source levels and suggested waveform
- number of elements in towed-array receiver
- length of towed array
- operating depth of receiver
- suggested signal processing approach (general type only)
- other specific parameters as needed.

Potential Impacts: Concurrent with the design effort is a project to address potential impacts to marine mammals from the introduction of the sound source incorporated into the active acoustic detection system. The work will produce a precis of existing auditory data on marine mammals. This compilation is needed to assess whether sufficient information exists to determine what species could be affected by long-range detection devices that may be employed in tuna fisheries. The proposed summary will be devoted primarily to a description of currently available data on marine mammal hearing and ear anatomy, a discussion of the methods used to obtain these data, the caveats entailed in cross-species/cross-modality comparisons, and a discussion of the forms and mechanisms of acoustic trauma in mammals in general. In addition, for those species for which existing data are sufficient, estimates of acoustic impacts from proposed tuna detection devices will be provided. The final section of the report will outline potential areas of research in which data are lacking and will attempt to prioritize them in terms of the potential acoustic fragility of the species and the feasibility of research, considering animal accessibility and applicable research techniques.

<u>Tuna Acoustic Parameters:</u> Extant modeling efforts incorporate known and assumed values related to individual tuna and tuna schools. Potential investigations of assumed parameters include 1) obtaining direct measurements of swimbladder volumes from large tuna, 2) direct measurements of active target strength returns from schools of yellowfin tuna, 3) direct measurements of passive signatures from schools of tuna, and 4) frequency distributions for tuna school packing density, length distributions, and swimming depths.

We plan to obtain swimbladder volumes from large yellowfin tuna collected aboard long-range sportfishers. Individual fish would be dissected and the swimbladder volume obtained through immersion in water. A preliminary effort is underway to perform this task using frozen tuna.

US Navy systems exist with which direct measurements of both active and passive target strengths of tuna schools could be obtained. Fish Aggregating Devices moored near the Hawaiian Islands attract schools of tuna and would be a relatively easy location to deploy these systems with a high probability for success.

Optical Detection Systems

<u>Active Detection Systems:</u> Another high priority future project is to model the propagation characteristics and laser power intensities of practical, airborne lidar systems. The Dolphin-Safe Research Program has investigated three Lidars: 1) the NMFS-lidar field tested during 1992, 2) the Kaman Aerospace Corporation's FISHEYE imaging lidar, and 3) the evolving NOAA-lidar operated by the Environmental Technology Laboratory (ETL) in Boulder, Colorado.

Under a currently funded project, ETL will develop a model to estimate the performance of the NOAA lidar for tuna detection under conditions typical of the tropical Pacific. This will include maximum depth penetration for typical ranges of packing densities and detection probabilities for typical ranges of school size and depth parameters. The swath width of the NOAA lidar can easily be varied, and the effects of doing that will be investigated. A wider swath increases coverage. It also can provide deeper penetration because multiply scattered photons are detectable. However, it can also degrade performance, especially during the day, because more background light is admitted into the detector. Polarization can also be varied in the NOAA lidar, and the effects of this will be studied. Ship data suggest that detecting the unpolarized component of the scattered light might provide the best signal.

The current effort will use mathematical models to ascertain the relative importance of various model parameters in achieving the goal of airborne optical detection, and to provide an analysis of potential designs and performance expectations for a specified range of detection depths, area coverage, costs, and platforms. The project report will address the ETP optical environment as it affects the detection and localization of tuna within the mixed- layer, using optical systems which are deployable from tuna purse-seiners during normal fishing operations. The report will describe and/or estimate the optical target strength of tuna and tuna schools using existing data, and address maximizing the depth at which tuna can be detected and localized leading to capture. The results will provide information for developing and evaluating lidar detection proposals, and for directing future Dolphin-Safe Program research into the design and development of lidar detection systems for large yellowfin tuna in the ETP.

We also plan to continue our involvement in the development of the NOAA lidar and to participate in a third series of lidar field experiments planned for 1997.

<u>Potential Impacts:</u> Following the modeling of performance characteristics and expected laser power densities, the next project planned would address potential impacts to marine animals from the introduction of the laser light into the sea. The effort will be directed at producing a precis of the state of the art of vision data on marine animals. This compilation is needed to assess whether sufficient information exists to determine what species could be affected by the laser power associated with lidar detection devices that may be employed in tuna fisheries. The effort will include a description of currently available data on marine mammal vision and eye anatomy, a discussion of the methods used to obtain these data, the caveats entailed in cross-species/cross-modality comparisons, and a discussion of the forms and mechanisms of laser trauma in mammals in general. In addition, for those species for which existing data are sufficient, estimates of laser impacts from proposed lidar detection devices will be investigated. An outline of potential areas of research in which data are lacking will be compiled.

<u>Passive Detection Systems:</u> Although passive, multispectral systems cannot see as deeply as lidar systems and are operable only during daylight, they are less expensive and have the potential to see deeper than human observers. Arete' Associates results from a SBIR grant suggest that the technology is practical, but fish school images are currently unavailable. With the acquisition of a 3-chip CCD camera system, we plan on obtaining target images of fish schools during 1997. Subject to funding, we propose to have these images processed by Arete' Associates as a demonstration of the technology, and to develop a final design for an airborne system.

Tuna Optical Parameters: Extant modeling efforts incorporate known and assumed values related to individual tuna and tuna schools. Potential investigations of assumed parameters include 1) obtaining direct measurements of 532nm laser light reflectivities from large tuna, 2) direct measurements of passive reflectivities from schools of yellowfin tuna, and 3) frequency distributions for tuna school packing density, length distributions, and swimming depths.

We propose to obtain laser and passive (sunlight) reflectivities from large tuna maintained in captivity. Fish Aggregating Devices moored near the Hawaiian Islands attract schools of tuna and would be a relatively easy location to deploy airborne systems to measure reflectivities with a high probability of success.

Radar Detection Systems

Tuna School Parameters: The modeling efforts by Summers (1996) concluded that direct measurements of radar backscatter from tuna schools and from bird flocks associated with tuna schools are needed to accurately assess the detection limits of X-band and S-band radars. The equipment to collect these data are readily available, but access to large numbers of tuna schools and bird flocks is difficult to obtain without a dedicated research vessel operating in the ETP. Potential platforms of opportunity include tuna vessels willing to carry a scientist, NOAA vessels conducting marine mammal surveys and Scripps Institution of Oceanography vessels.

We plan to initiate contacts with radar manufacturers on the potential to develop larger radar antennas optimized for the detection of birds flocks and to investigate display options which might help fishermen detect and track both bird flocks and fish schools.

Although not part of our current studies, the successful use of a SLAR (Side-Looking Airborne Radar) Ato detect tuna in the Seychelles at wind speeds up to 20 kts and distances, under ideal conditions, exceeding 35 km@, (Lyne et al., 1992), may warrant investigation.

Fish Aggregating Devices

From our investigations, and those of others, drifting FADs can be constructed and deployed at little cost and, in some instances, quickly aggregate large amounts of bigeye, yellowfin, and skipjack tuna (among other species). Anchored FADs also are capable of attracting large quantities of tuna but require greater expense (mooring) and maintenance, and are prone to theft or destruction. Future FAD efforts will require a dedicated vessel and scientists to deploy and monitor FADs for fish aggregations and collect environmental data. Such efforts should be directed to the more offshore areas of the ETP where the larger yellowfin tuna are generally found in association with dolphins.

If FADs are to be used as an alternative to dolphin-fishing, then the bycatch issue must be addressed. Studies should be initiated to reduce the bycatch of non-target species that currently occur with this type of fishing. Potential investigations should include 1) determining whether a vertical or horizontal separation occurs between target and non-target species in the purse-seine net using underwater videos, and 2) development of gear modification or procedures to reduce bycatch mortality. For example, vertical or horizontal separation may provide for the release of non- target species by lowering the corkline or installing a hard or soft release grating in the purse-seine.

Summary

The Dolphin-Safe Research Program has completed two of three successive research cycles, and is currently nearing completion of the third cycle. The first cycle answered affirmatively the initial question of whether large yellowfin tuna are ever unassociated with dolphins in the ETP, and therefore might be available in commercially adequate numbers. The second cycle determined first, that locating such fish should be possible given the physical oceanographic environment of the ETP, and second, that the most appropriate medium to long range detection devices would be acoustic. Local detection could be improved over current methods by using newly developed and developing optical detection technologies (i.e., lidar and enhanced video). During the third (and last) research cycle, the Dolphin-Safe Research Program will determine the specifications for the optimal acoustic system for locating large unassociated yellowfin tuna in the ETP, and initiate planning for research surveys to determine distribution, abundance, and commercial potential of the resource.

If pending legislation becomes law, the Dolphin-Safe Research Program focus will revert to emphasis on dolphin management and protection.

Acknowledgments

This report presents the purpose and a brief summary of results for projects performed by a great many people. Successful development and conduct of these research efforts were due solely to the dedication and efforts of the scientists, fishermen, and contractors who performed the work. We thank each and every one of the people who participated in the various projects and shared their data with us.

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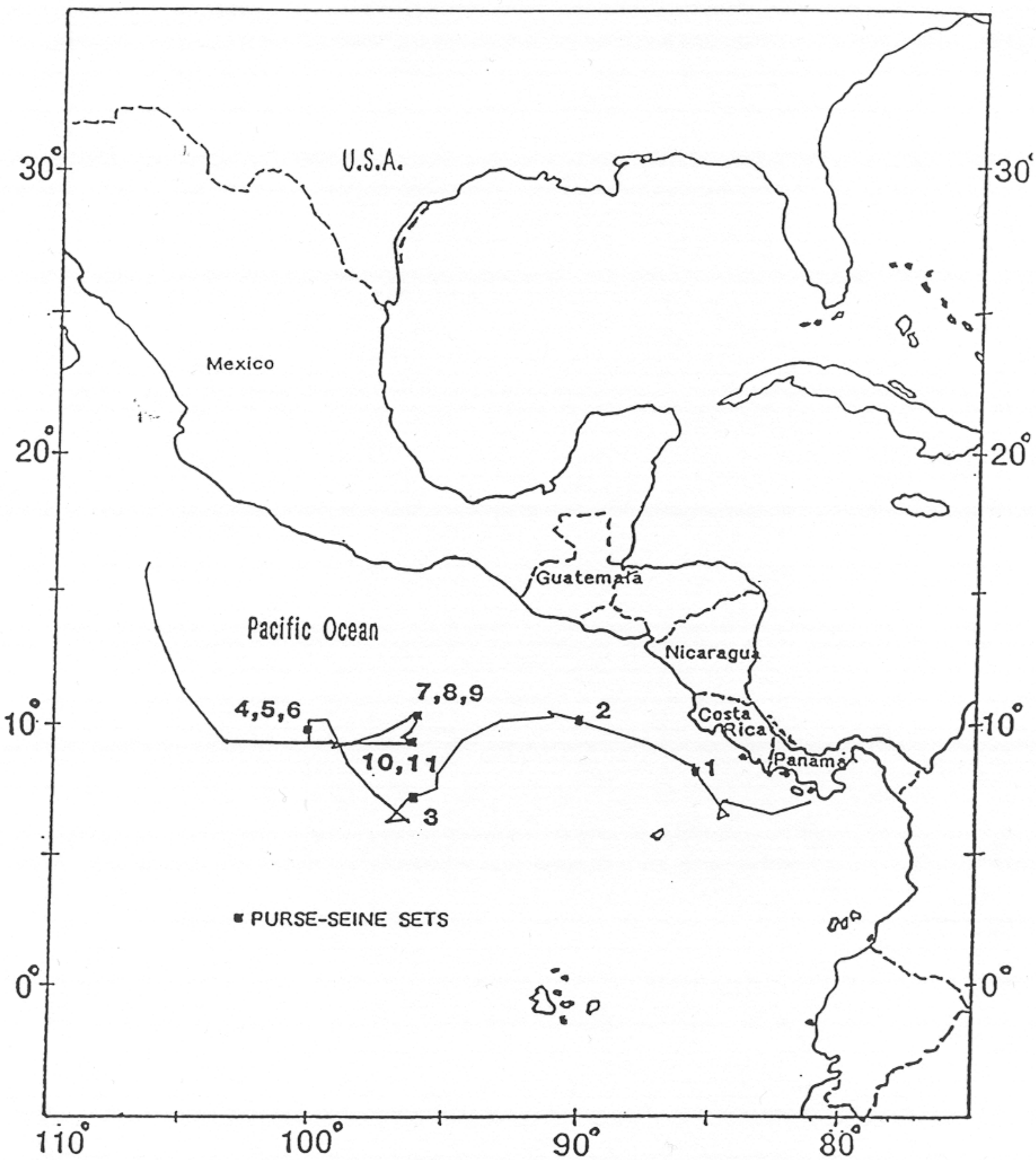


Figure 1. Cruise track and set locations for the 1992 IATTC/NMFS tuna/dolphin tracking cruise November 4 - December 7, 1992.

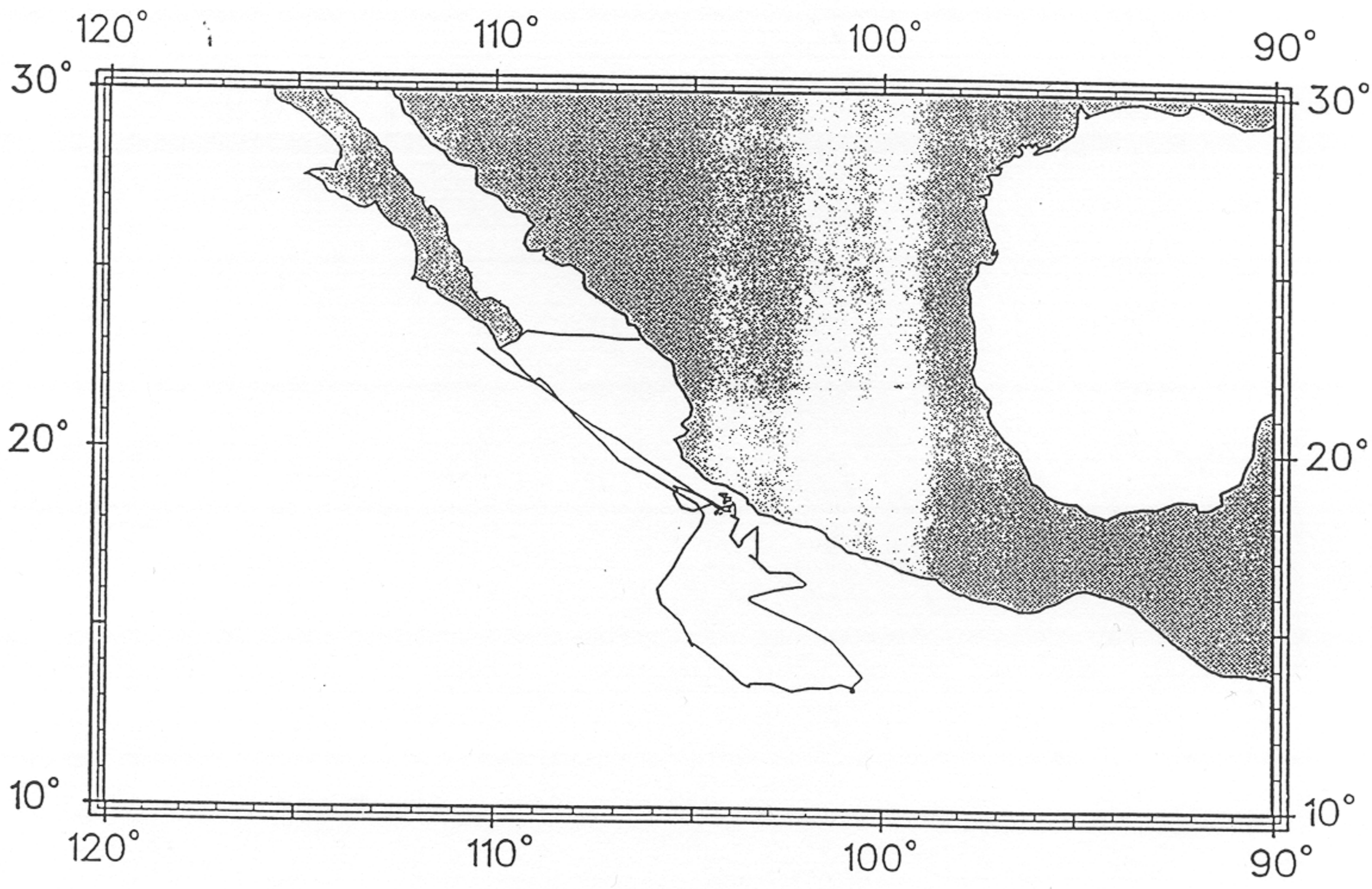


Figure 2. Cruise track and set locations for the 1993 IATTC/NMFS tuna/dolphin tracking cruise November 6 - December 5, 1993.

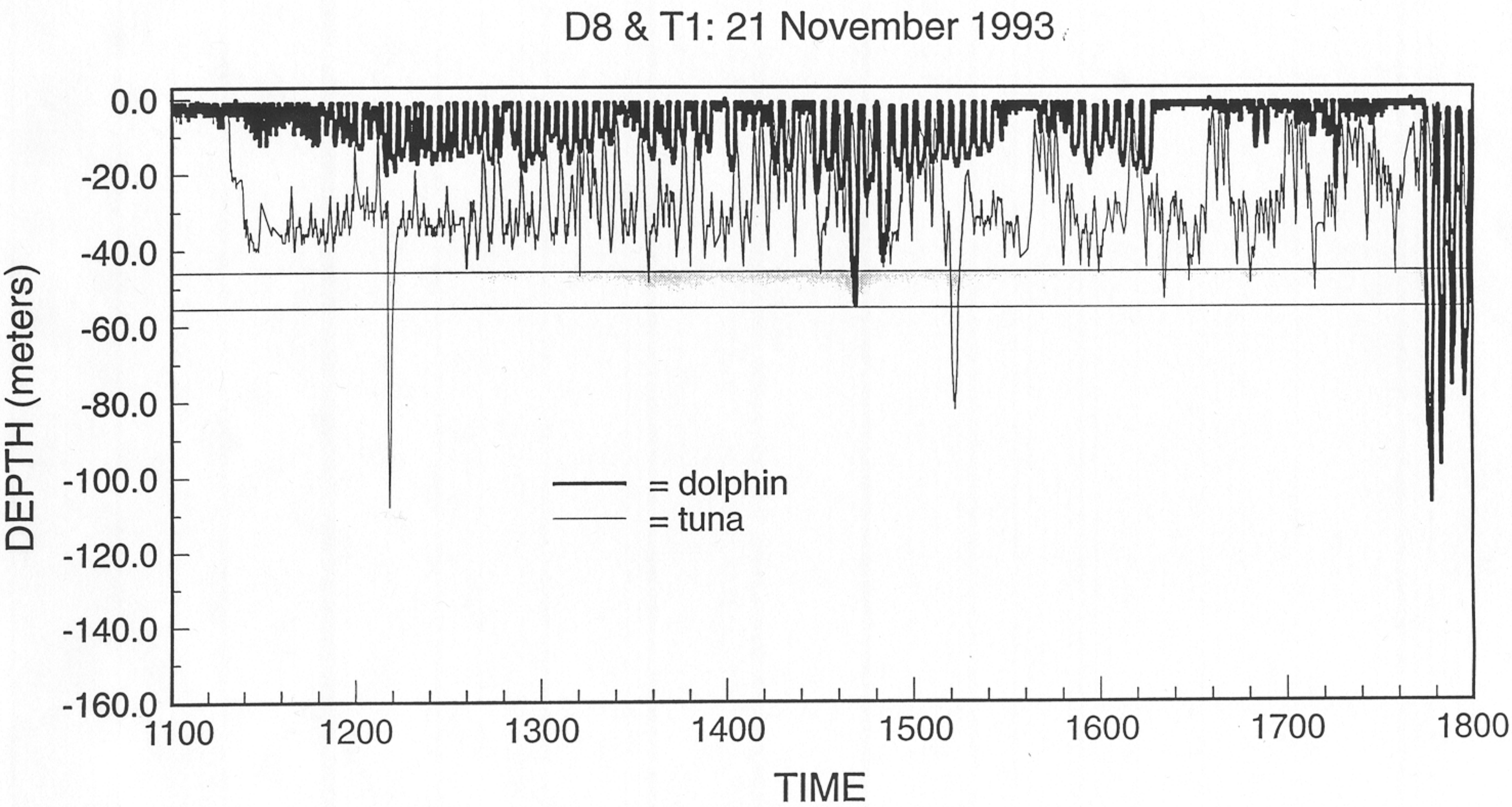


Figure 3a. Continuous time/depth tracks for a spotted dolphin and a yellowfin tuna on November 21, 1993: 1100-1800 hours local time. (With permission, Michael Scott, IATTC).

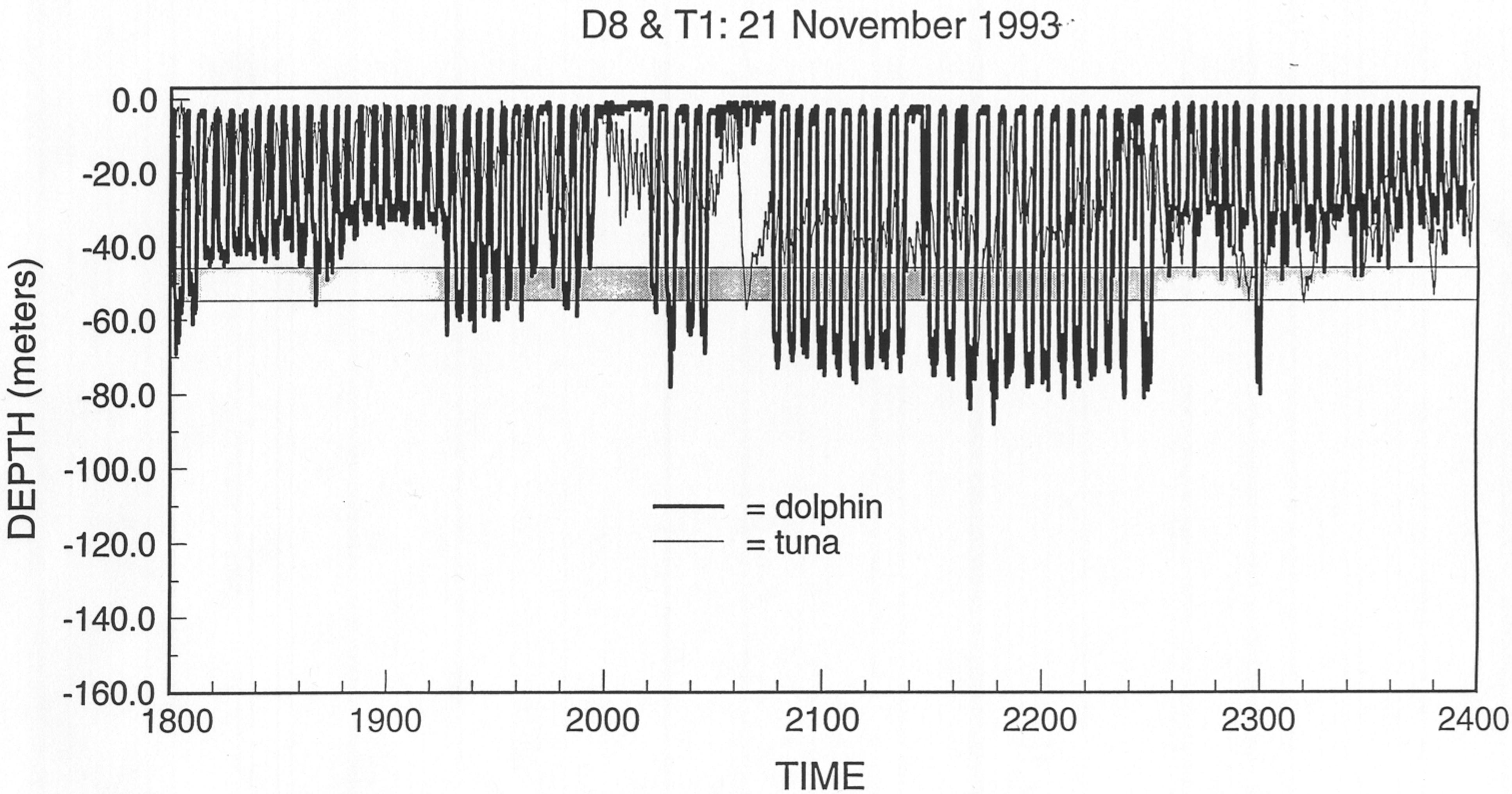


Figure 3b. Continuous time/depth tracks for a spotted dolphin and a yellowfin tuna on November 21, 1993: 1800-2400 hours local time). (With permission, Michael Scott, IATTC).

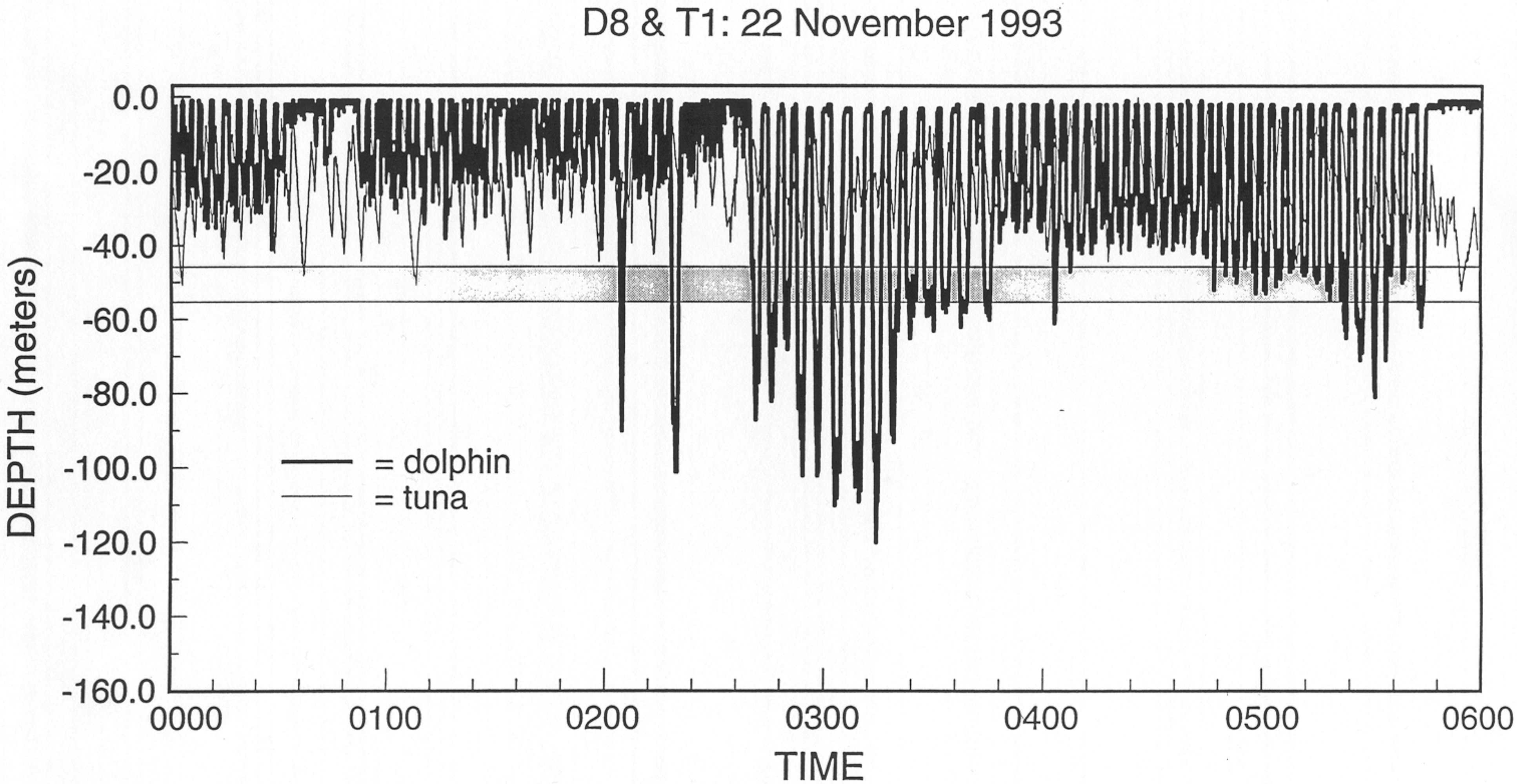


Figure 3c. Continuous time/depth tracks for a spotted dolphin and a yellowfin tuna on November 22, 1993: 0000-0600 hours local time). (With permission, Michael Scott, IATTC).

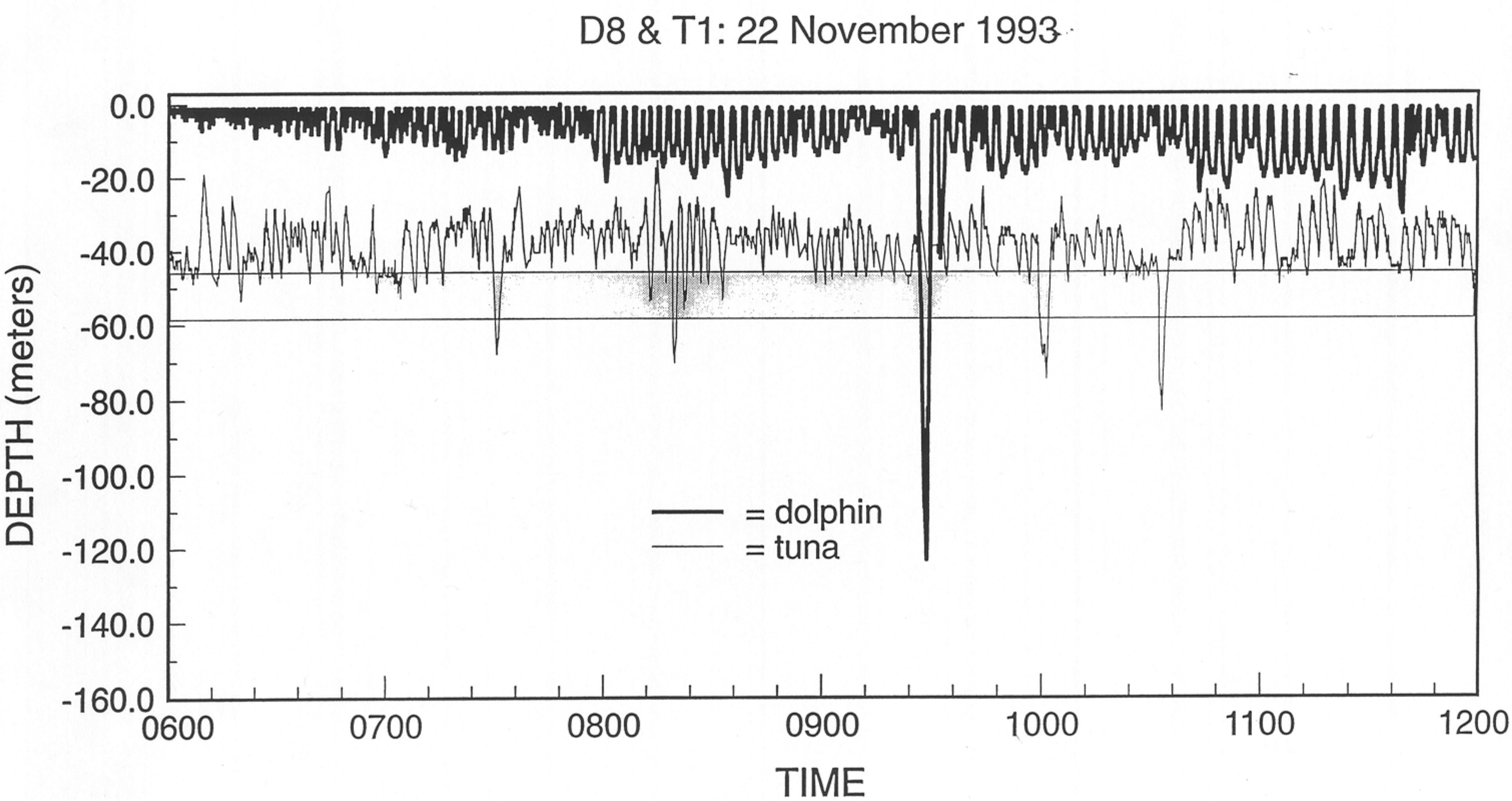


Figure 3d. Continuous time/depth tracks for a spotted dolphin and a yellowfin tuna on November 22, 1993: 0600-1200 hours local time). (With permission, Michael Scott, IATTC).

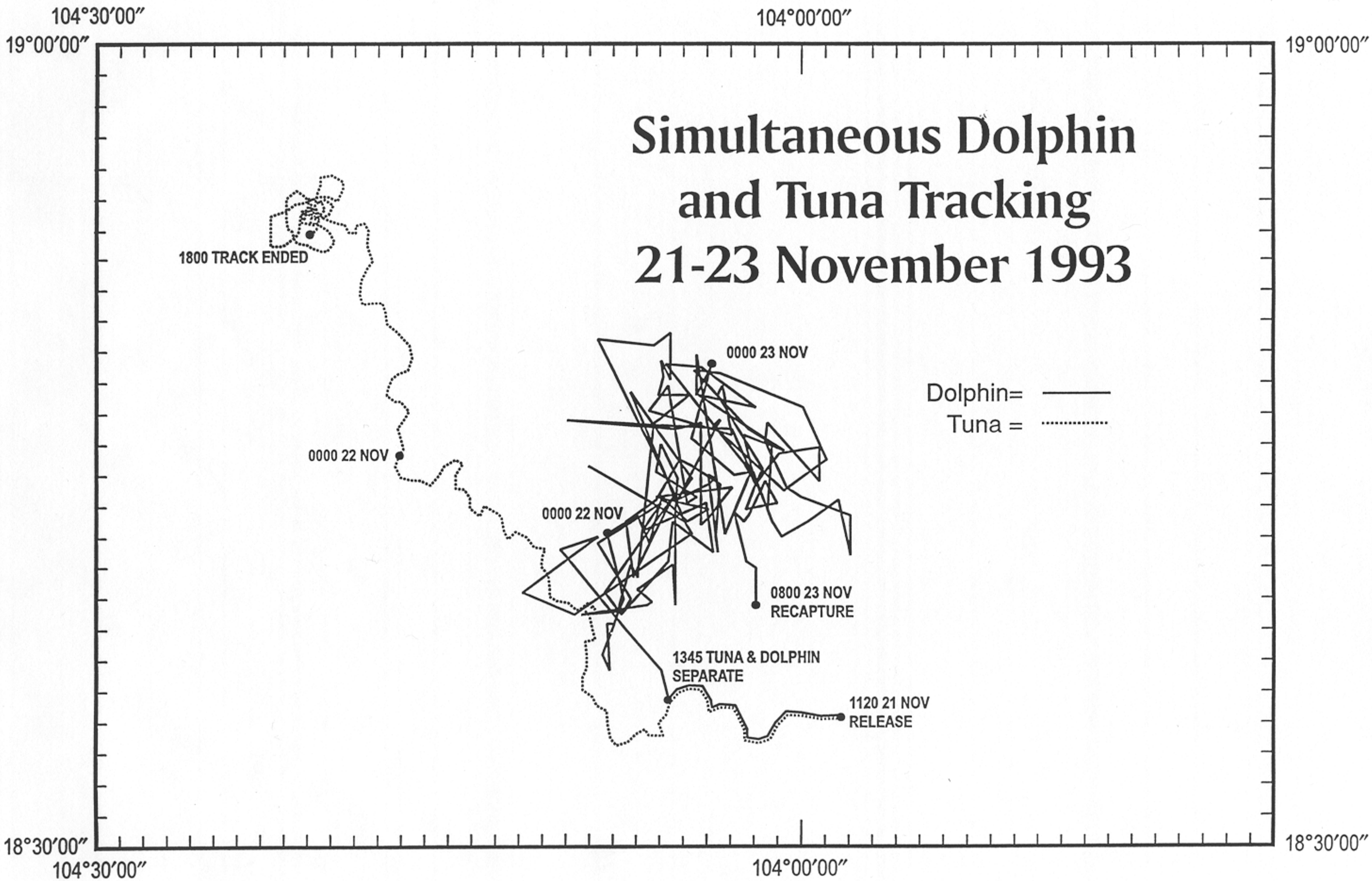
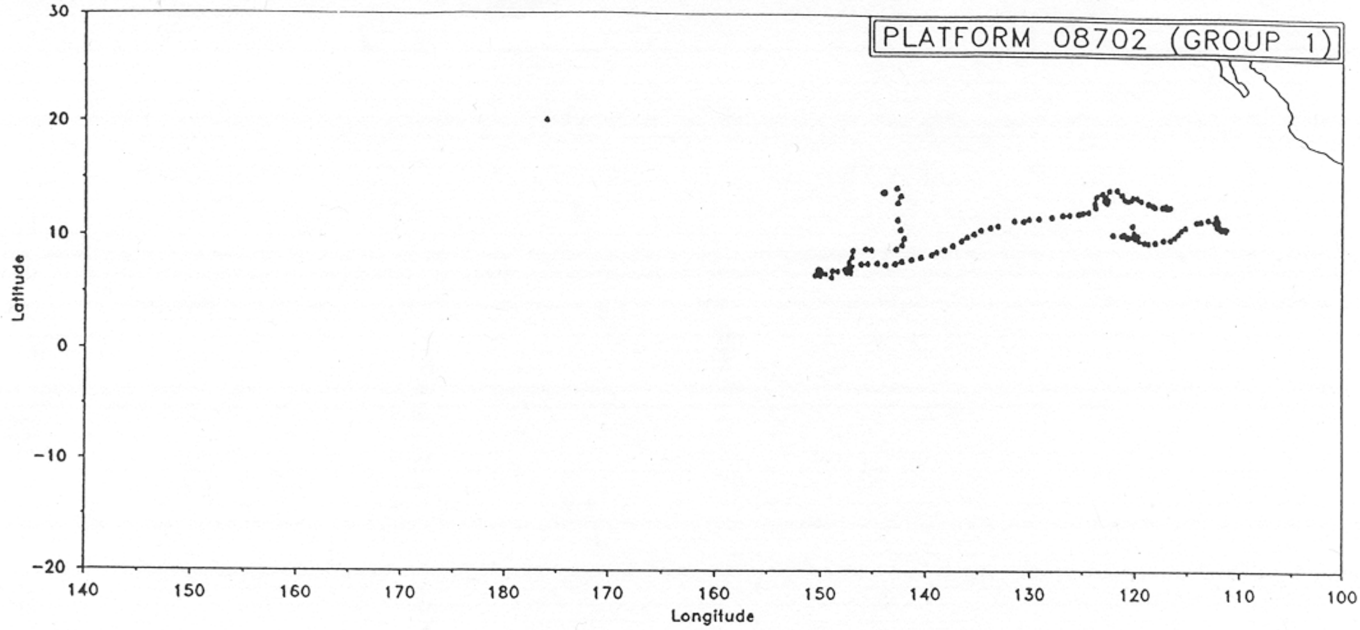


Figure 4. Simultaneous spatial tracks of a spotted dolphin and yellowfin tuna between November 21-23, 1993. (With permission, Michael Scott, IATTC).



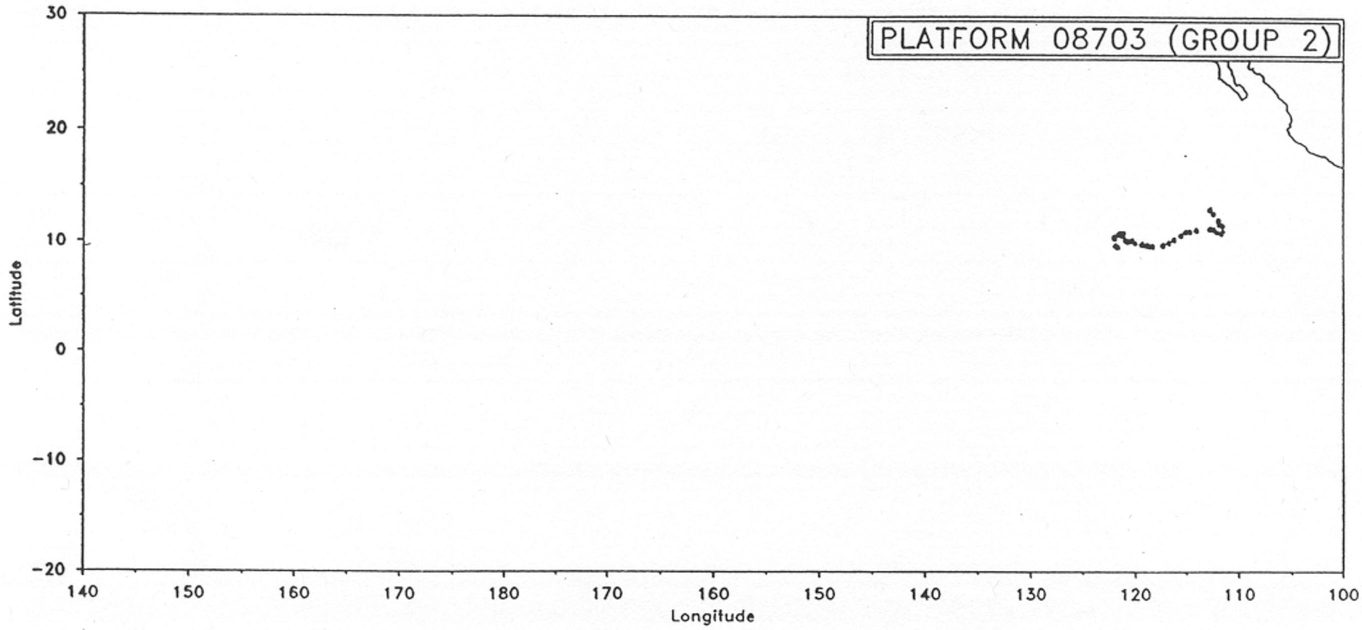
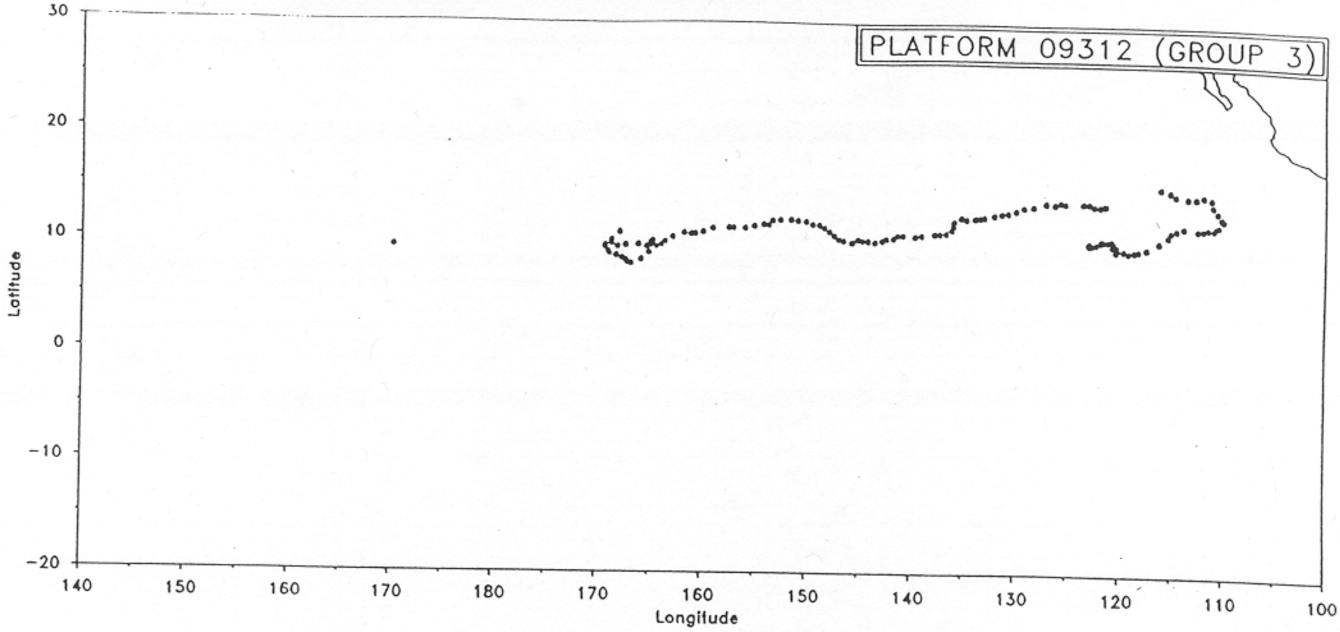


Figure 5a. Positions obtained through the ARGOS satellite system for Group 1 FADS between 22 July 1991 and 18 April 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

Figure 5b. Positions obtained through the ARGOS satellite system for Group 2 FADS between 22 July 1991 and 6 November 1991. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.



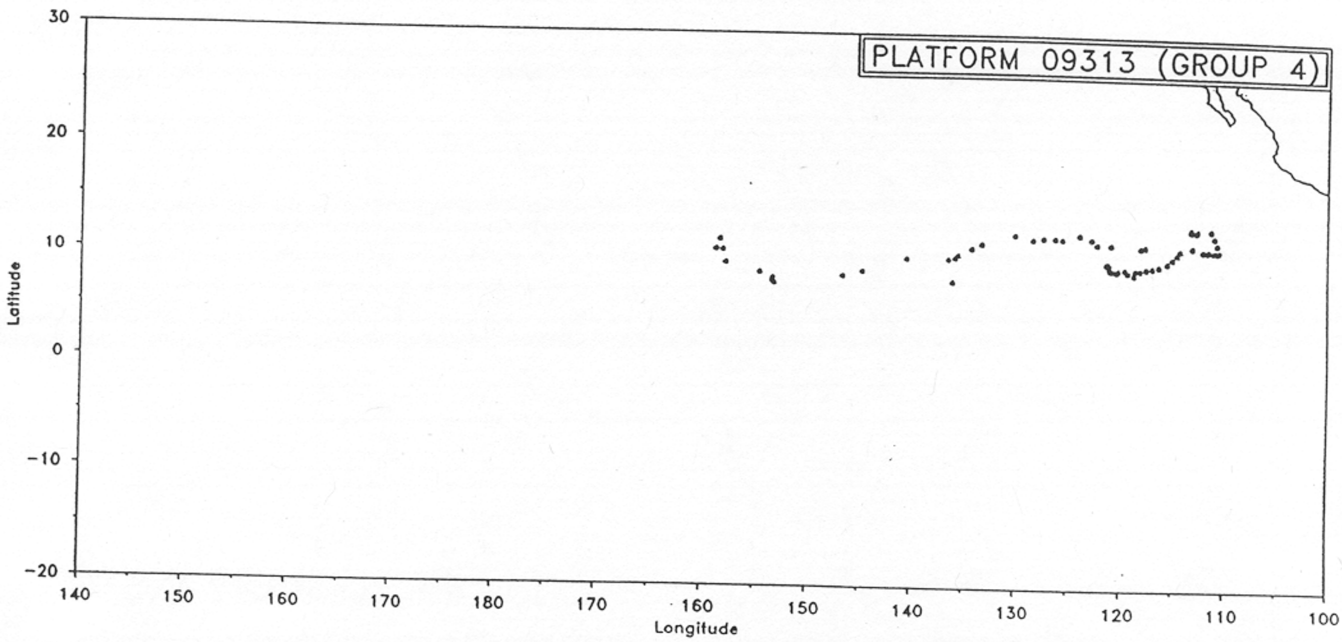
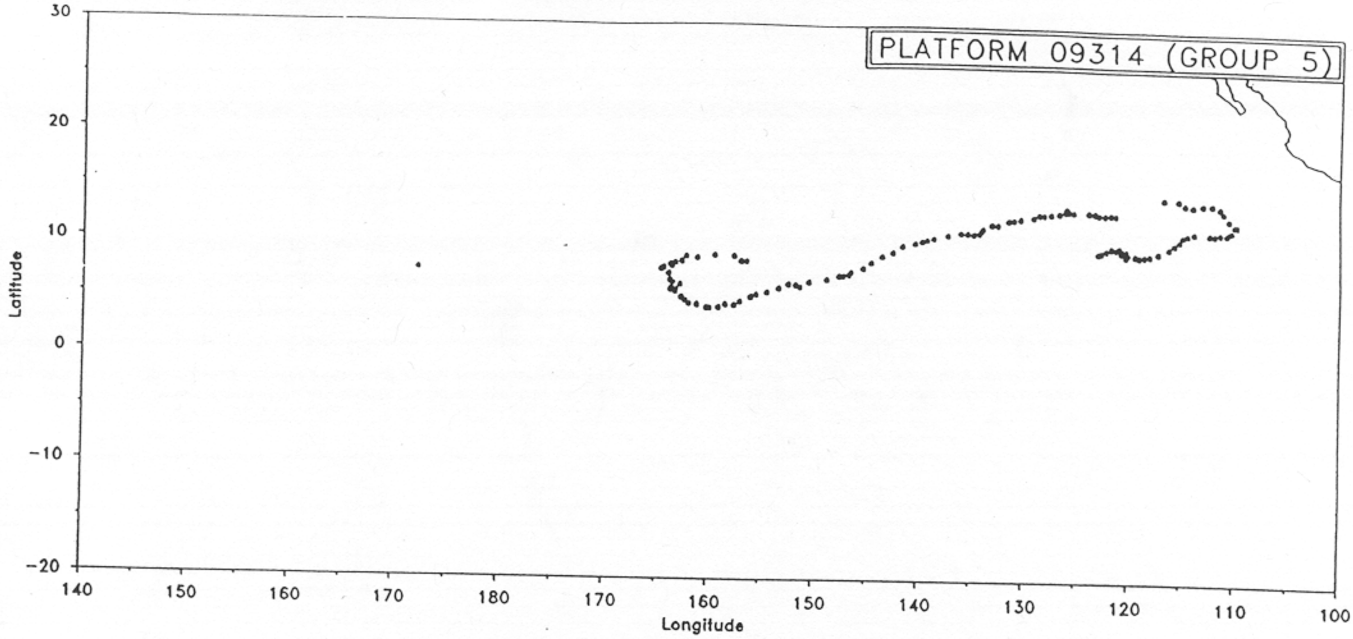


Figure 5c. Positions obtained through the ARGOS satellite system for Group 3 FADS between 23 July 1991 and 4 April 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

Figure 5d. Positions obtained through the ARGOS satellite system for Group 4 FADS between 22 July 1991 and 30 September 1992. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.



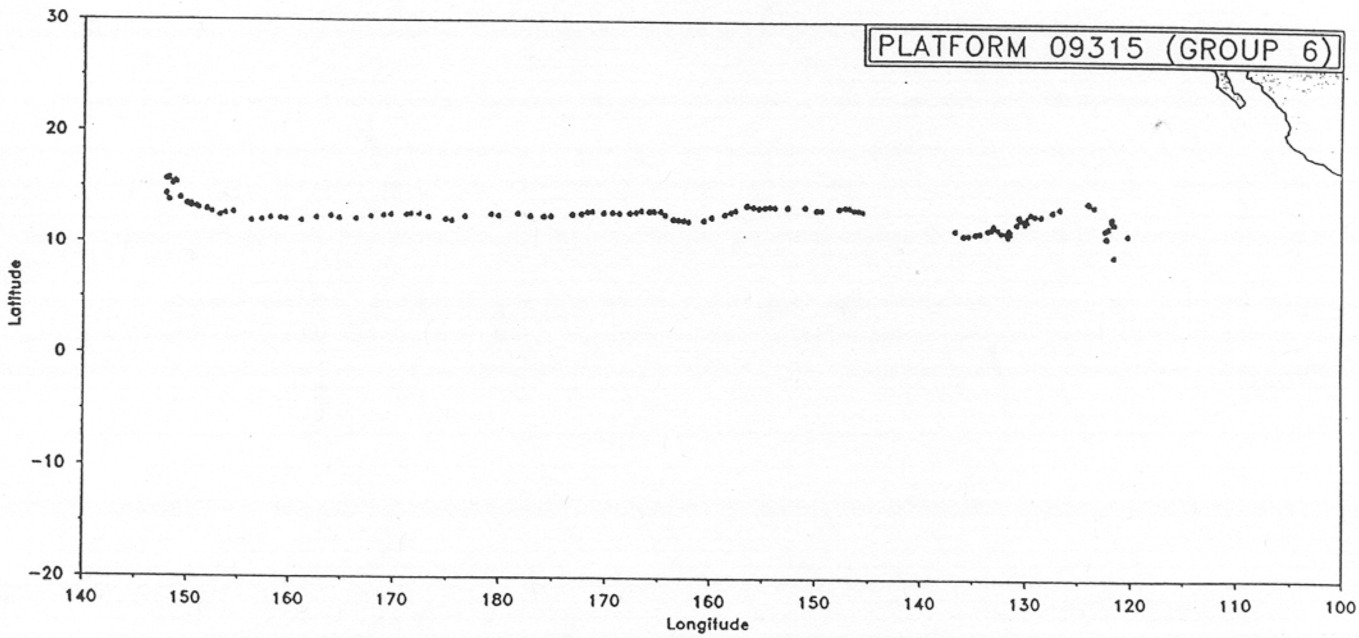
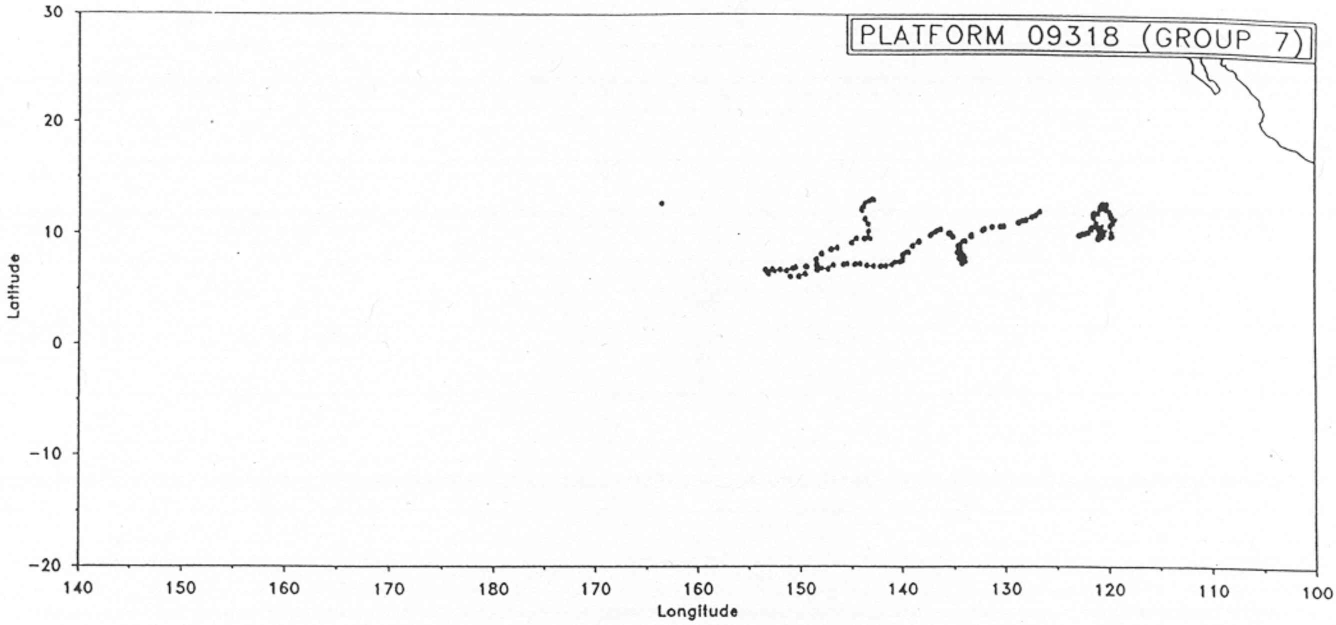


Figure 5e. Positions obtained through the ARGOS satellite system for Group 5 FADS between 23 July 1991 and 5 March 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

Figure 5f. Positions obtained through the ARGOS satellite system for Group 6 FADS between 23 July 1991 and 24 February 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.



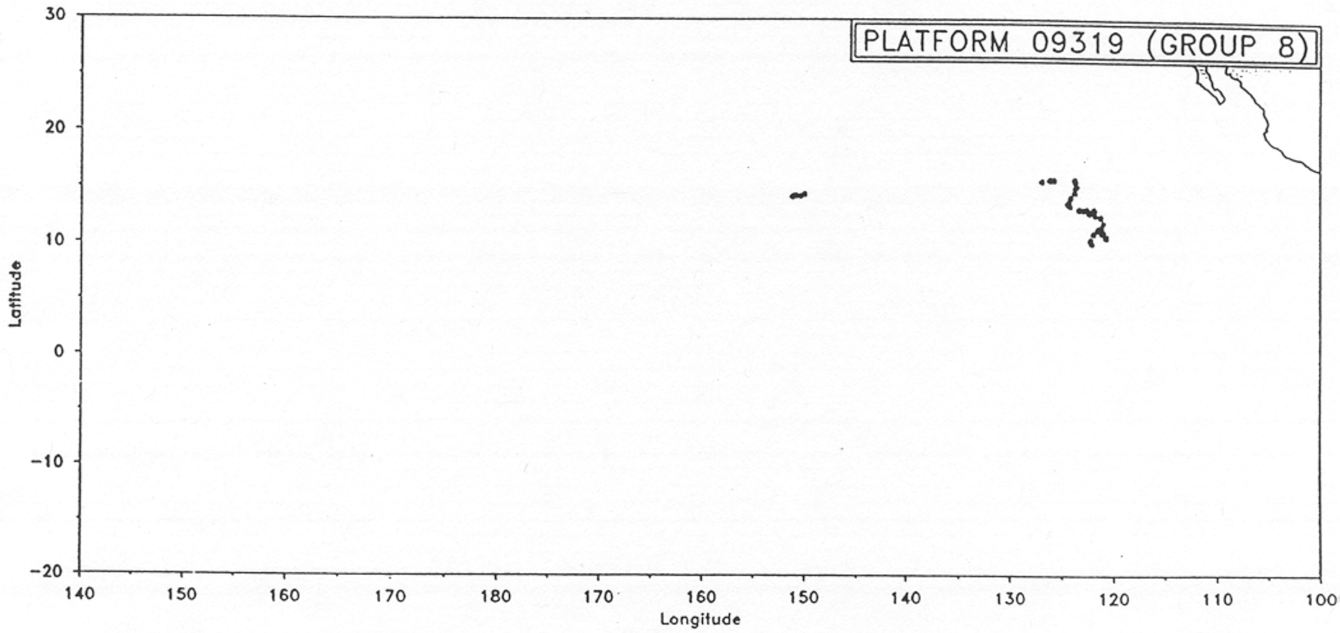
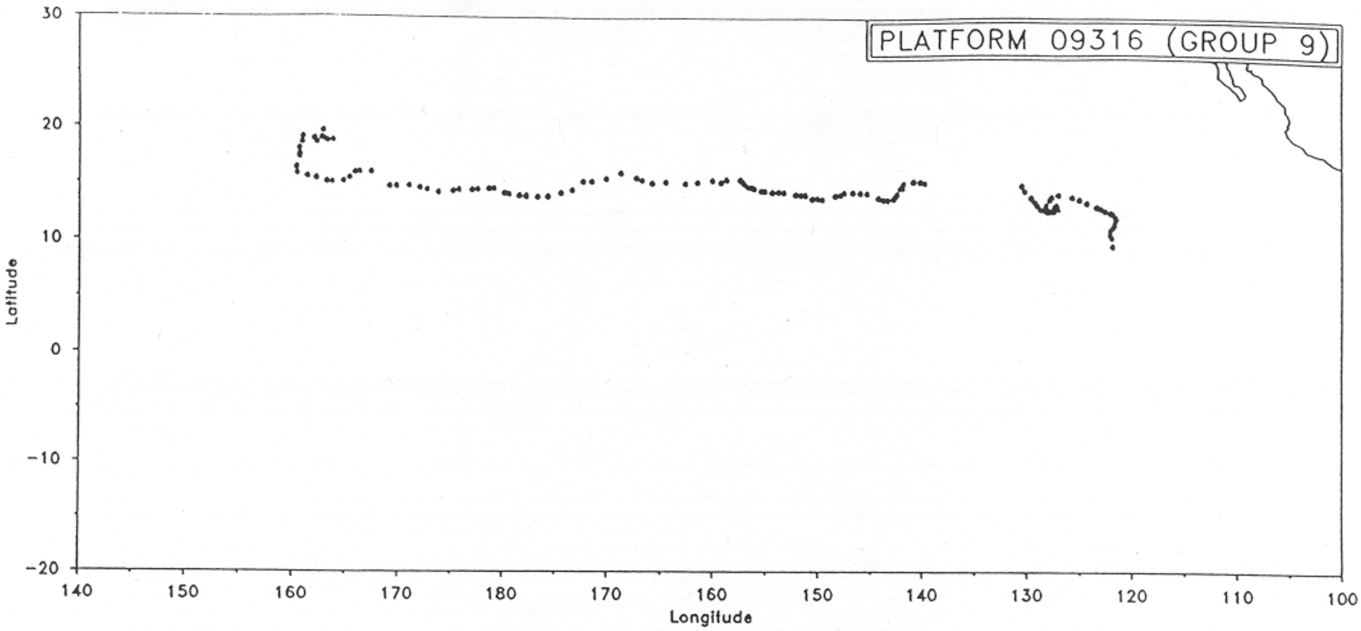


Figure 5g. Positions obtained through the ARGOS satellite system for Group 7 FADS between 23 July 1991 and 19 January 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

Figure 5h. Positions obtained through the ARGOS satellite system for Group 8 FADS between 23 July 1991and 5 February 1992. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.



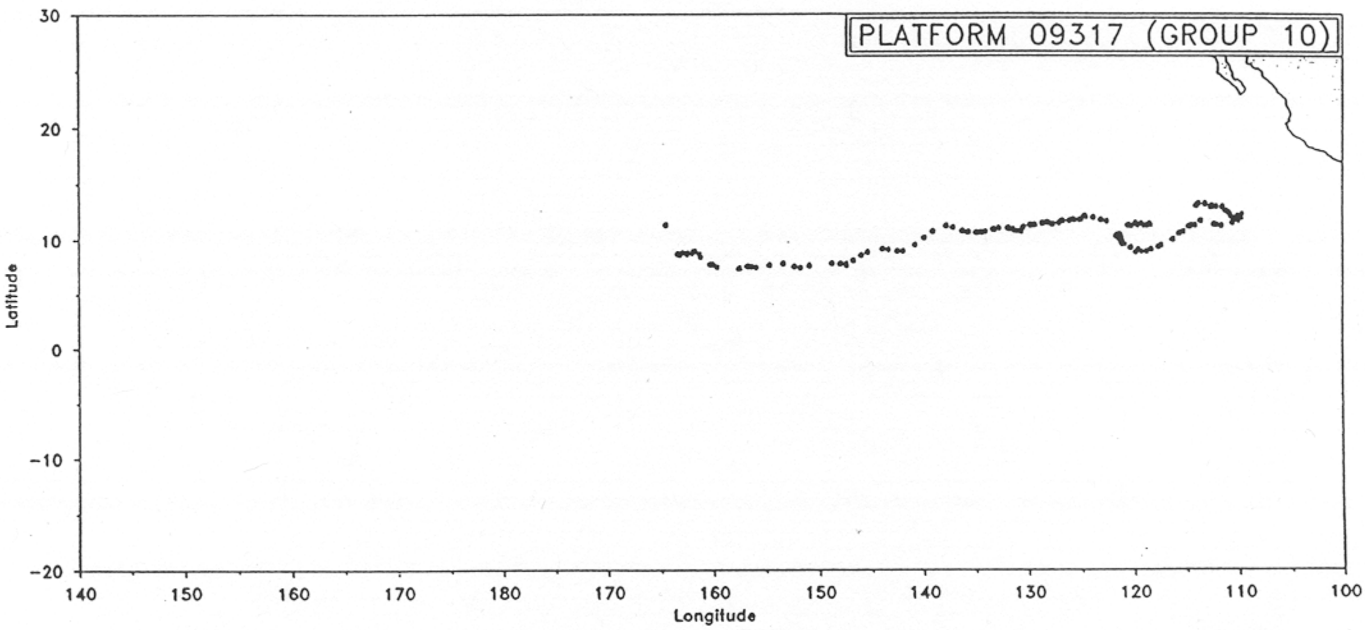


Figure 5i. Positions obtained through the ARGOS satellite system for Group 9 FADS between 23 July 1991 and 3 January 1993. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

Figure 5j. Positions obtained through the ARGOS satellite system for Group 10 FADS between 22 July 1991 and 14 September 1992. Position data were obtained more frequently (daily versus once a week) early in the joint IATTC/NMFS drifting FAD experiment.

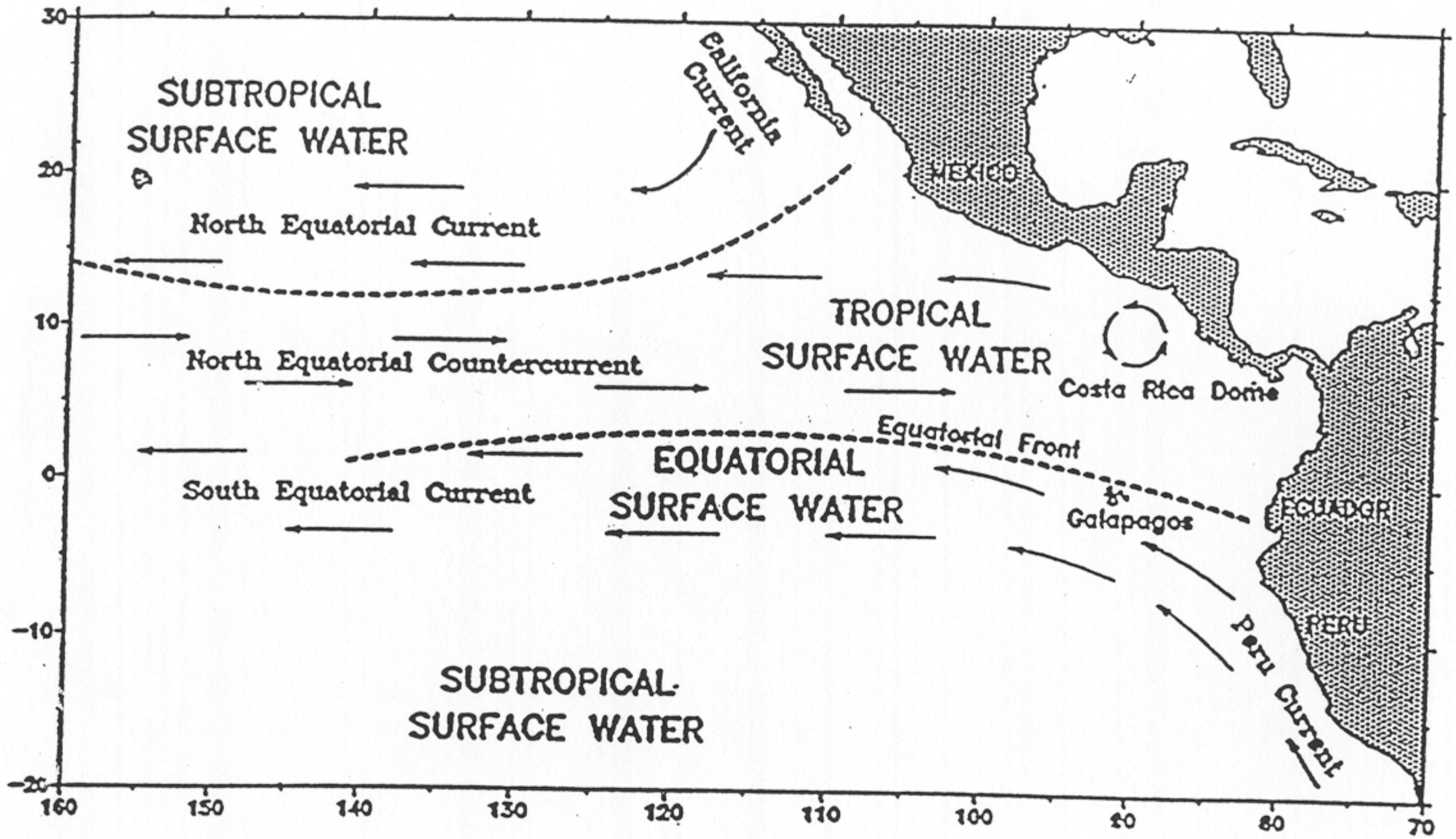


Figure 6. Typical surface water circulation patterns in the Eastern Tropical Pacific Ocean. From Wyrtki (1967): Circulation and water masses in the eastern equatorial Pacific Ocean. Int. J. Oceanol. Limnol. 1:117-147.

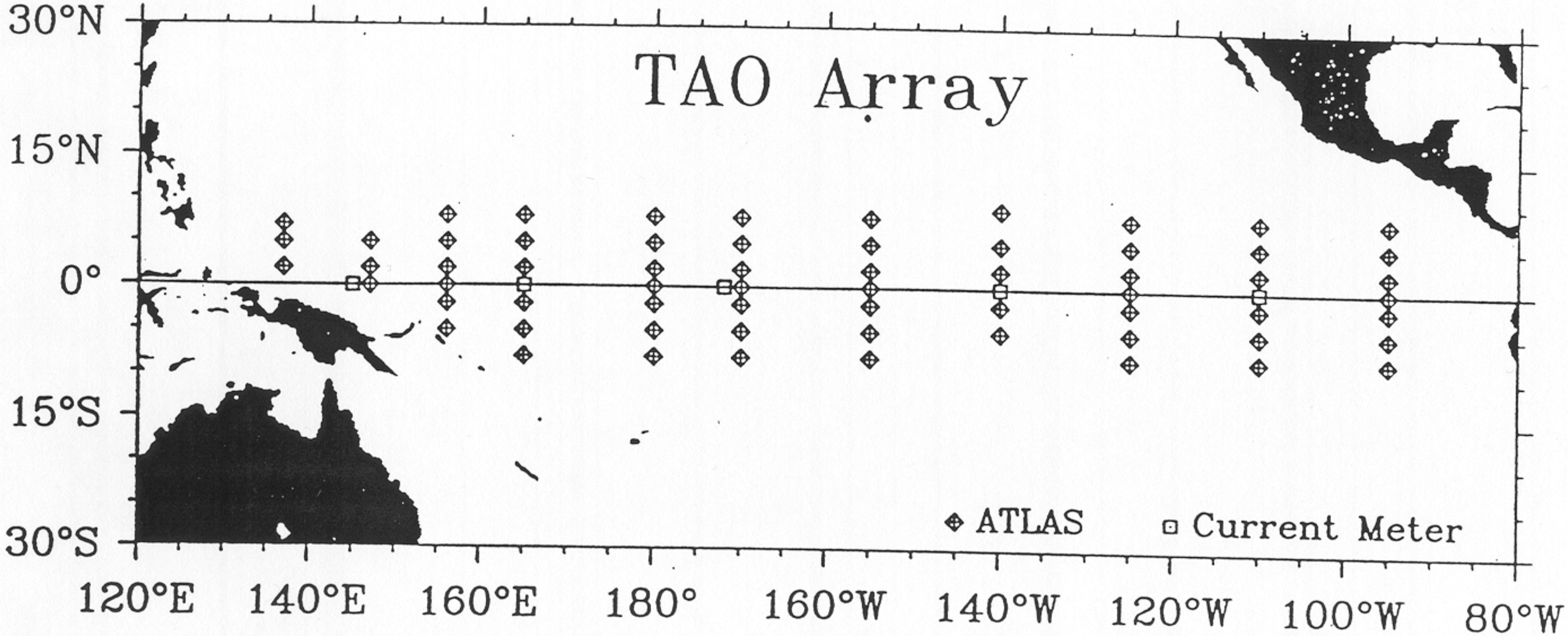


Figure 7. Mooring locations of Tropical Atmosphere Ocean (TAO) Atlas buoys and current meters in the equatorial Pacific Ocean (Freitag et al., 1995).

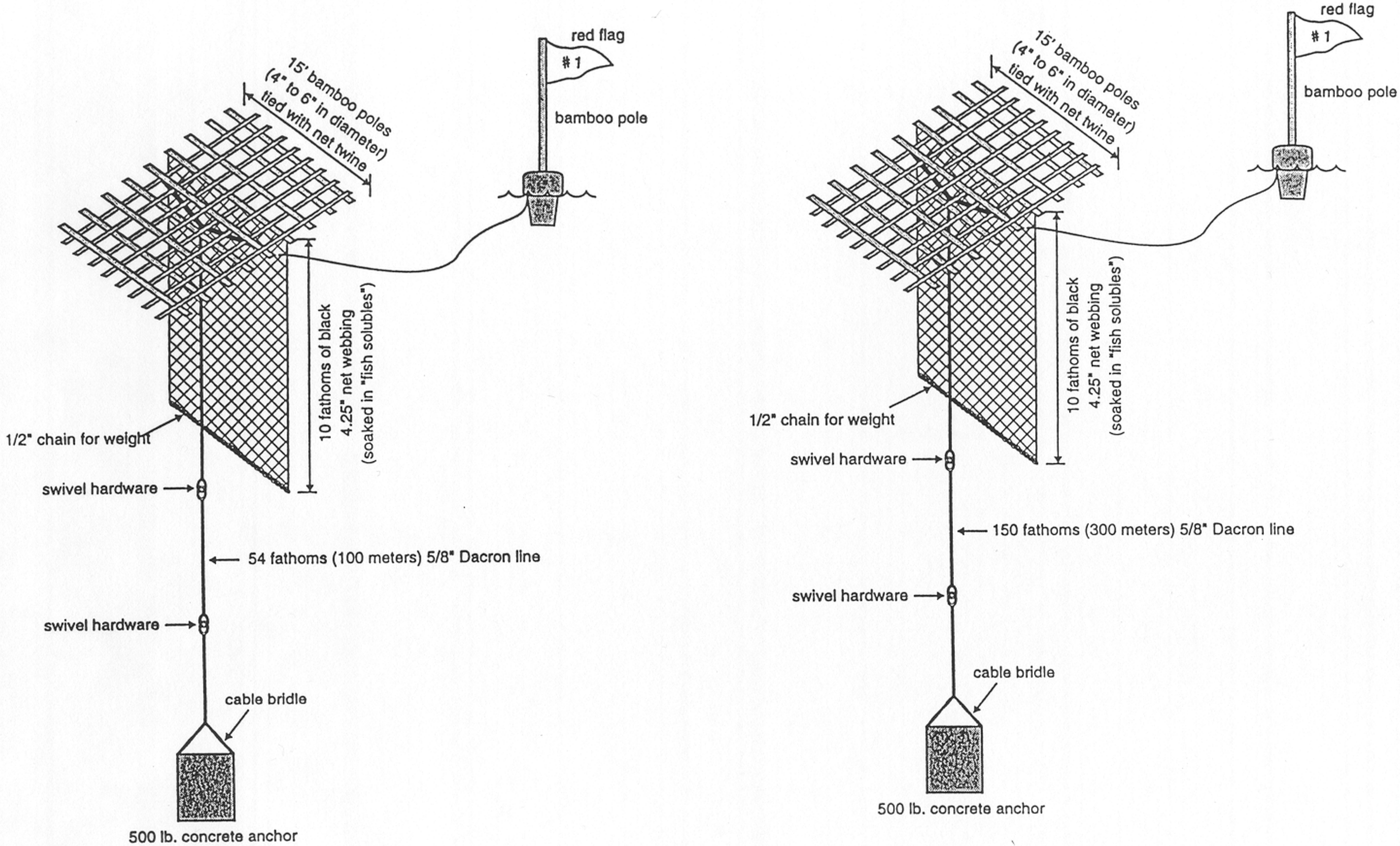


Figure 8. General design for an anchored Fish Aggregating Device (FAD) used by Captain Richard Stephenson in the eastern tropical Pacific Ocean.

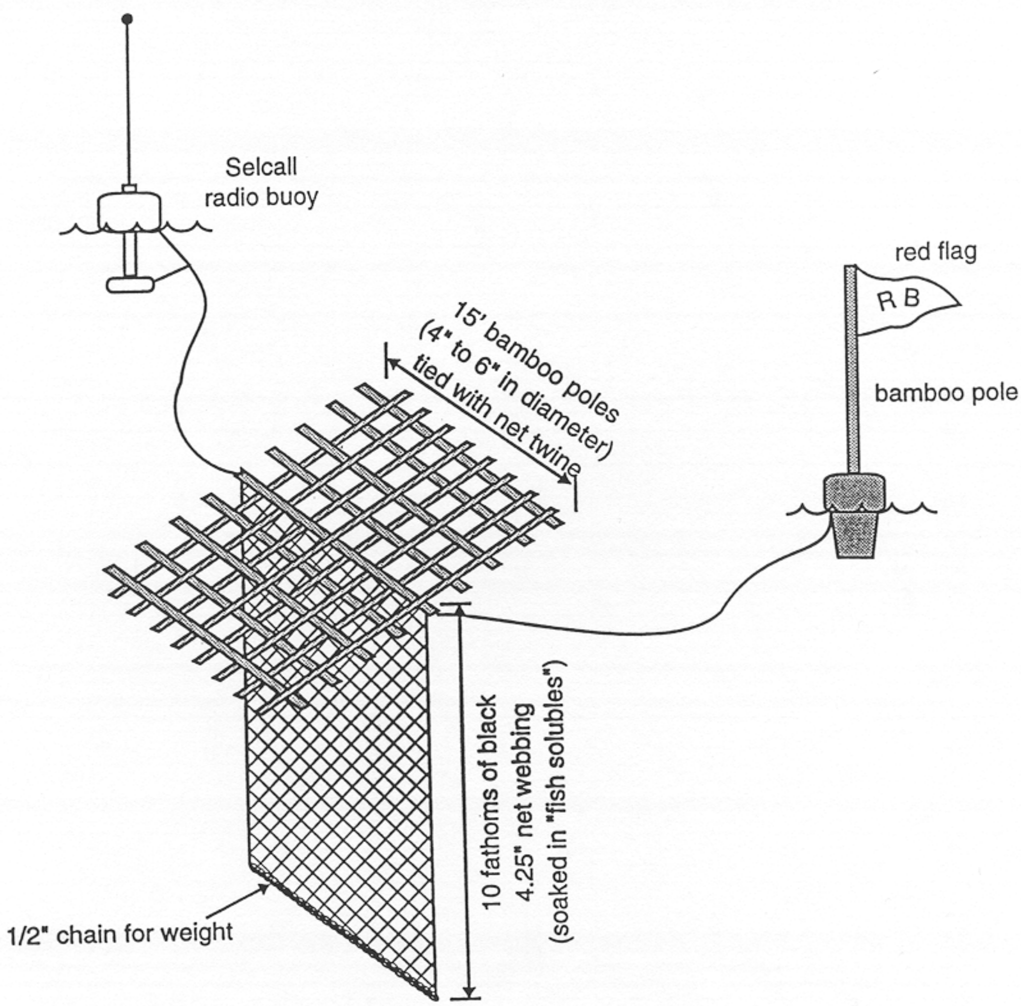


Figure 9. General design for a drifting Fish Aggregating Device (FAD) used by Captain Richard Stephenson in the eastern tropical Pacific Ocean.

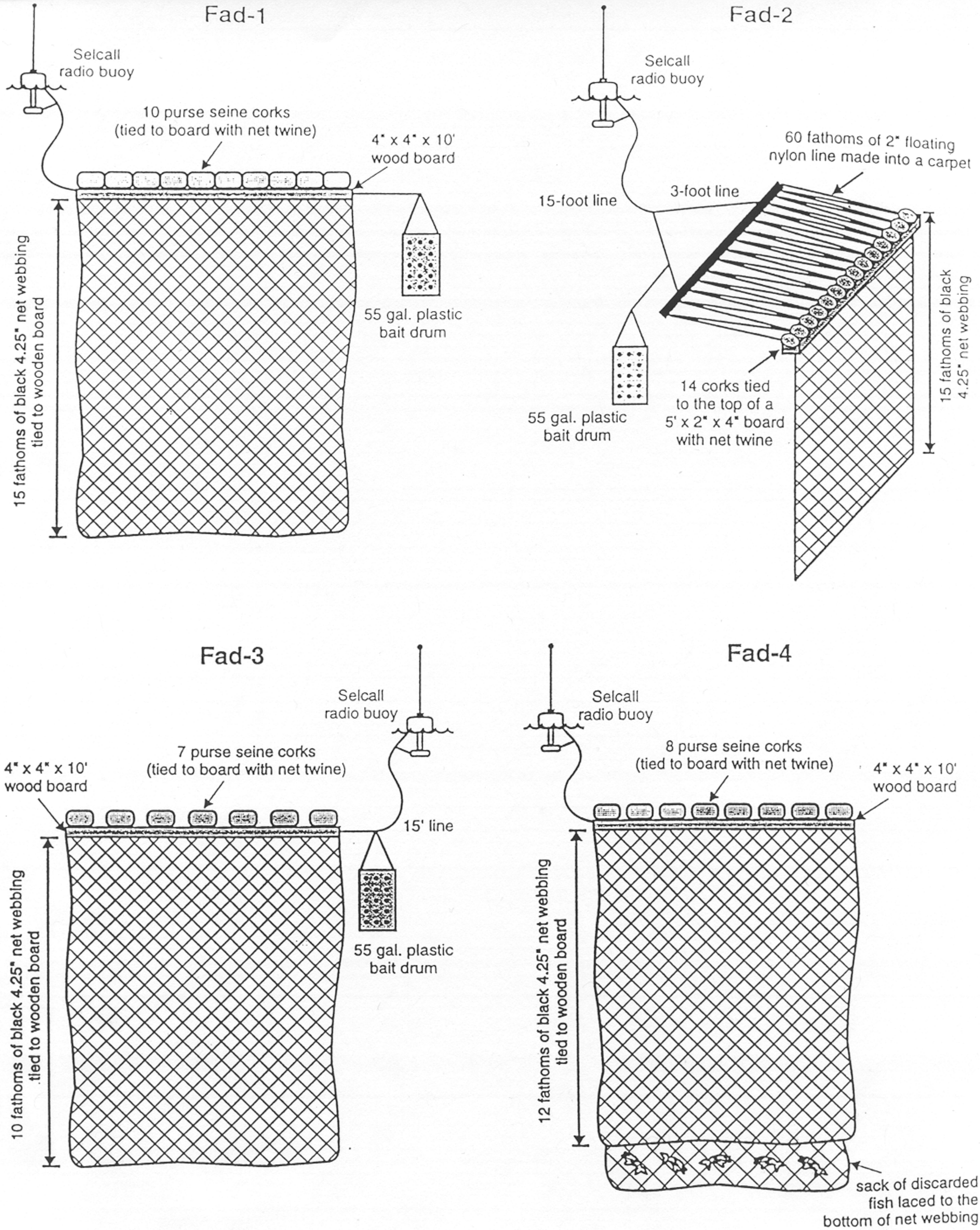


Figure 10. General designs for drifting Fish Aggregating Devices (FADs) used in the eastern tropical Pacific Ocean.

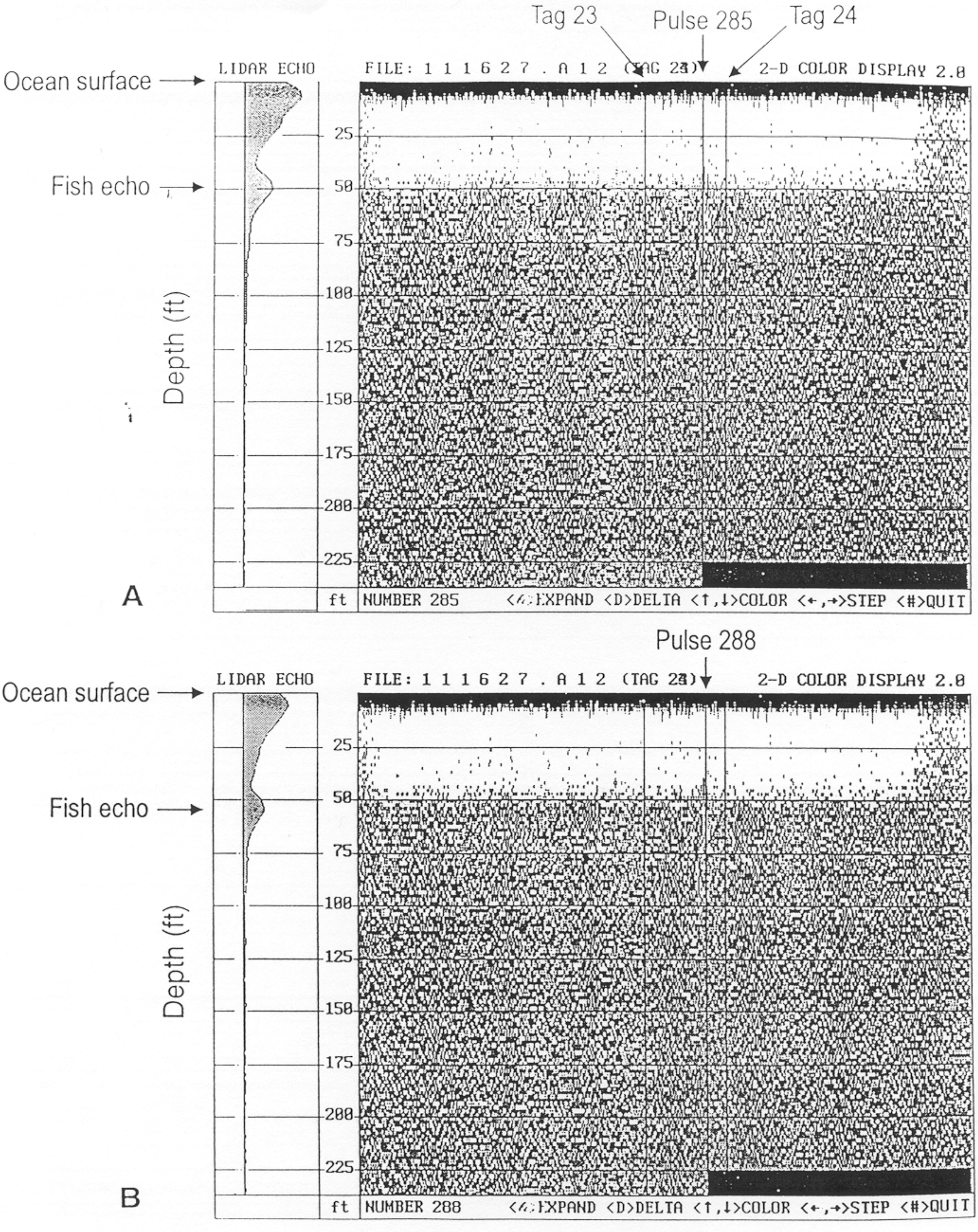


Figure 11. NMFS LIDAR display taken October 12, 1992 showing the detection of a tuna school, within a purse-seine net, at depths between 9-15 meters at pulse 285 (A), and between 11-17 meters at pulse 288 (B).

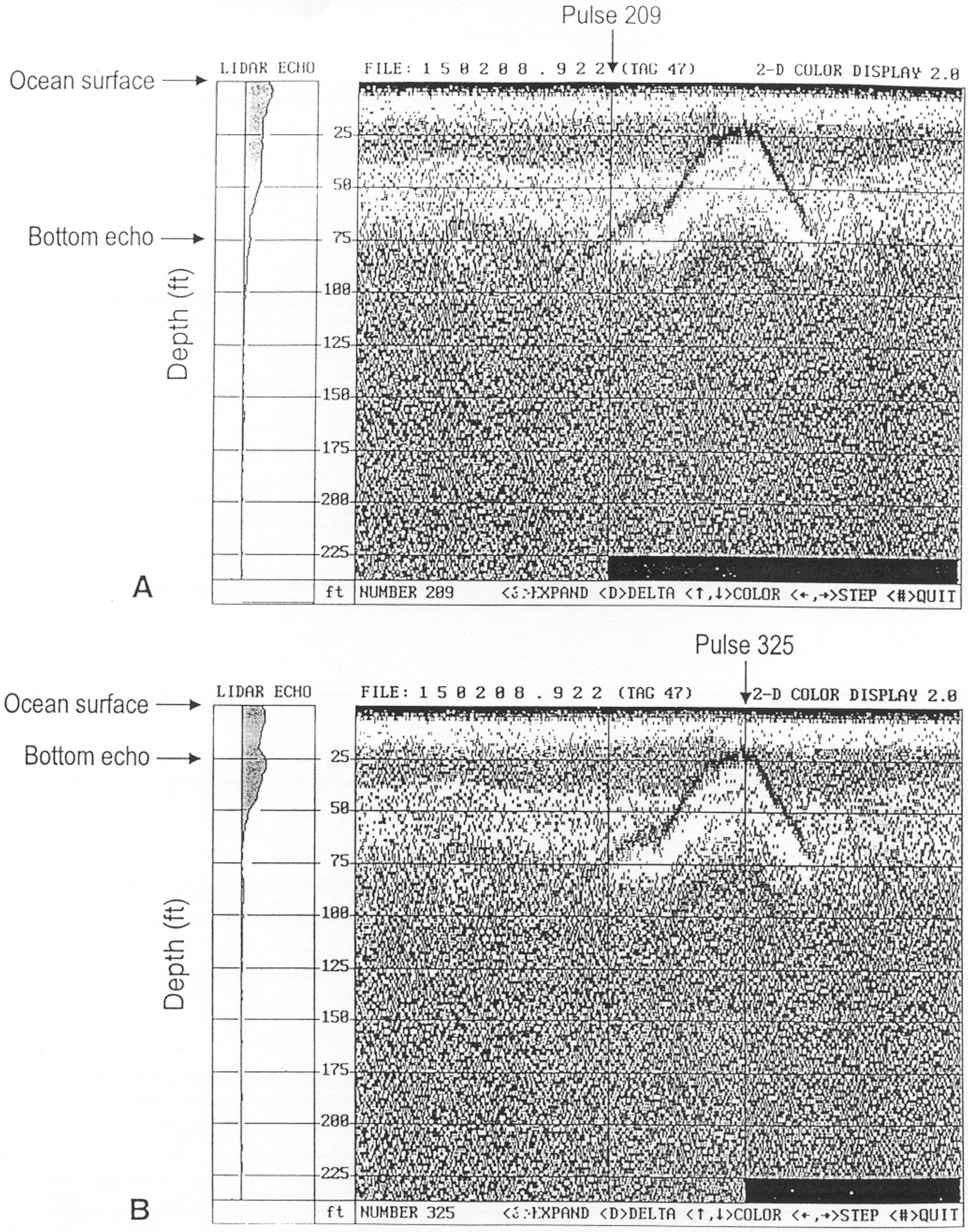


Figure 12. NMFS LIDAR display taken September 22, 1992 showing the ocean bottom contour at depths from 24 meters at pulse 209 (A), rising to a depth of 6 meters at pulse 325 (B).

Table 1. Proposal categories for technologies to detect tuna schools not associated with dolphins.

	Method of Tuna Detection	
	Direct	Indirect
Acoustics (Ship, Helicopter, FAD)		
Side-looking sonar	*	
Look-down sonar	*	
Scanning sonar	*	
Passive hydrophones	*	*
Passive sonarbuoys	*	*
Passive resonance techniques	*	*
Optics (Ship, Helicopter)		
Radiometric lidar	*	
Imaging lidar	*	*
Low-light video	*	*
High-resolution video	*	*
Hyper-sprectral imaging	*	
Fluoresence imaging	*	
Infrared imaging		*
Radar (Ship, Helicopter)		
Synthetic Aperture Radar (SAR)	*	*
Infrared radiometers		*
Microwave radiometers		*
Fish Aggregating Devices (FADS)		
Anchored	*	
Drifting with beacon	*	
Oceanographic indicators: Temperature, Salinity, Chlorophyll, Wind Speed Wind Direction, Currents (Satellite, Ship, Helicopter)		
Satellite SAR		*
Land-based radar		*
High-frequency radar		*
Infrared radiometers		*
Microwave radiometers		*

Enhancements to tuna detection - PATTERN RECOGNITION

Quantitative Echo Integration (Acoustics)
Neural Networks (All)
Artical Intelligence (All)
Multiple Sensor Integration or Fusing (All)
Image Enhancement (All)

Appendix 1. Solicited and unsolicited proposals investigated by the Dolphin-Safe Research Program during 1992-1996. Interested parties should contact the entity listed for more information.

A Proposal to Study the Density and Characteristics of Tuna School and Bird Flock Aggregations Not Associated within the ETP.
IATTC
Scripps Institution of Oceanography
La Jolla, CA 92037

Turner Buoy System
Eric S. and M. Elizabeth Turner
342 S. Jefferson Ave.
Louisville, CO 80027
(303) 665-6833

Hyperester Net Webbing
West Coast Netting INC.
Bill Kirkland, Pres.
8978 Haven Ave., P.O. Box 728
Rancho Cucamonga, CA 91730
(714) 987-4708

Catamaran "Fishing Platform"
Ocean Recovery Systems
David Young, General Mgr.
10540 Wilshire Blvd., Suite 205
Los Angeles, CA 90024
(310) 470-9513

Thomas Drop Nets
Net Systems Inc., Gary Loverich
7910 Day Road W.
Bainbridge Island, WA 98110
(206) 842-562

Net improvements
DBA Sara Scientific Co.
Sherman Fishman
295 Stevenson Dr.
Pleasant Hill, CA 94523

Measurements Program to Establish the Design Parameters for the Acoustic Detection and Control of Tuna Schools

Robert W. Jackman
575 W. Madison Ave., Apt. 58
El Cajon, CA 92020
(619) 579-9827

Study the acoustic spectrum produced by a swimming dolphin

Robert W. Jackman
575 W. Madison Ave., Apt. 58
El Cajon, CA 92020
(619) 579-9827

Development of an automatic fish classification and monitoring system using anti-submarine warfare technologies

ORINCON Corporation
Patrick K. Simpson, Principal Eng./Invest.
Richard L. Taylor, Dir. of Contracts
9363 Towne Centre Drive
San Diego, CA 92121
(619) 455-5530

Neural networks for forecasting fisheries stocks

ORINCON Corporation
Patrick K. Simpson, Principal Eng./Invest.
Richard L. Taylor, Dir. of Contracts
9363 Towne Centre Drive
San Diego, CA 92121
(619) 455-5530

Development, fabrication and verification, at sea, of an innovative system for the electrical control, separation from tuna, and zero-mortality release of dolphins during backdown operations in purse-seining

Technomare Enterprises
Dr. Renato F. Schettino
752 Thayer Ave.
Los Angeles, CA 90024
(310) 474-2869

Dual channel optical sensor for enhanced airborne underwater imaging

Dynamics Technology, Inc. (DTI)
C. Michael Dube
21311 Hawthorne Blvd., Suite 300
Torrance, CA 90503

Automated Airborne Tuna School Detector
Arete' Associates
Philip J. Davis, PhD.
P.O. Box 6024
Sherman Oaks, CA 91413

Feasibility Study: Acoustic Deterrence System for Yellowfin Tuna
Sonalysts, Inc.
John K. Menezes and Stephen W. Dolat
215 Parkway North
Waterford, CT 06385
(203) 442-4355

Anti-submarine warfare technology (sonar signal processing systems) will be used to automatically classify, differentiate, and monitor tuna and dolphin
Scientific Fishery Systems Corporation
Patrick K. Simpson
17436 Ashburton Rd.
San Diego, CA 92128
(619) 675-0962

Acoustic Tracking System
Coastal & Offshore Pacific Corp.
John D. Hall
2255 Ygnacio Valley Rd.
Suite T
Walnut Creek, CA 94598
(510) 937-1556

Evaluate the fluorescence properties of several species of marine fish and dolphins
Ciencia, Inc.
Dr. Salvador M. Fernandez
111 Roberts St., Suite C
East Hartford, CT 06108
(203) 528-9737

Airborne fish detecting Lidar
Remote Sensing Industries, Inc.
Robert W.L. Thomas/Brian Treadwell
P.O. Box 683
Eastham, MA 02642
(301) 982-0836

Midwater pair trawling for yellowfin tuna in the ETP
Shuman Trawl
Paul Shuman
339 Church St.
Wood River Junction, RI 02894
(401) 364-8989

Airborne tuna locator (Lidar)
Grams Environmental Labs
Clyde M. Wyman/Gerald W. Grams
5767 Brooklyn Ln.
Norcross, GA 30093
(404) 321-4380

A more comprehensive analysis of dolphin low frequency sound transmission and the reception mechanisms of migratory tuna
Robert W. Jackman
575 W. Madison Ave., Apt. 58
El Cajon, CA 92020
(619) 579-9827

Forward Looking Infrared System to detect tuna
FLIR Systems
16505 S.W. 72nd Ave.
Portland, OR 97224
(503) 684-3731

TOF scanning laser system to detect tuna
Thermo Electron Technologies Corporation
Dr. Douglas Palmer
9550 Distribution Avenue
San Diego, CA 92121-2305
(619) 578-5885

Install, Operate and Report Results from an Airborne Lidar Used for Extended At-Sea Field Testing During Tuna Purse Seine Operations
TITAN CORPORATION
Dr. Jeffrey J. Puschell/Ms. Sandra A. Feldman
Titan Systems Group
5910 Pacific Center Blvd.
San Diego, CA 92121
(619) 546-9569/(619) 546-9642

Imaging Lidar to detect tuna
Kaman Aerospace Corporation
Kirk Daniels-Program Manager
P.O. Box 2
Bloomfield, CT 06002

Testing Lidar at sea aboard a commercial tuna purse-seine vessel
Kaman Aerospace Corporation
5055 E. Broadway
Suite C-104
Tucson, AZ 85711

Development of an active sonar system to detect and classify schools of tuna at long range, and development of a passive acoustic classification system that can verify the presence or absence of dolphins in tuna schools
ORINCON Corporation
3366 N. Torrey Pines Ct.
La Jolla, CA 92037

Long-Range Sonar Fish Detection: A Defense Conversion Opportunity for the Tuna Industry
Scientific Fishery Systems, Inc.
Patrick K. Simpson
17436 Ashburton Road
San Diego, CA 92128
(619) 675-0962

Human Line
Dolphin Coalition
c/o Nueva America Internacional
M. Alberto Rossi
10th Ave. 47th St. Colina Park
Apt. #2, Las Yosas
San Jose, Costa Rica
P.O. Box 130-2120
Tel-(506) 53-5749
Fax-(506) 24-1478

Dual Channel Imager for Enhanced Marine Species Monitoring
Dynamics Technology, Inc.
C. Michael Dube and Richard Chiles
21311 Hawthorne Blvd., Suite 300
Torrance, CA 90503

Tel: (310) 543-5433
Fax: (310) 543-2117

Bioacoustics/Behavioral Investigation Supporting the Development of Dolphin-Free Tuna Harvest
Analysis & Technology
Peter M. Scheifele
258 Bank St.
P.O. Box 1631
New London, CT 06320
(203) 444-0827

Development of a submersible, ultrasonic-frequency generator (marine mammal acoustic repellent system)
Robert Kracauer
253 W72nd St.
Apt. #1204
New York, NY 10023

Bioacoustical/Behavioral investigation supporting the development of dolphin-free tuna harvest
Analysis and Technology, Inc.
Peter M. Scheifele
28 Bank Street, P.O. Box 1631
New London, Ct. 06320
(203) 444-0827

Dual channel imager for enhanced subsurface fish detection and monitoring
Dynamics Technology, INC.
21311 Hawthorne Boulevard
Torrance, California 90503

Detection and Monitoring of Whales with Synthetic Aperture Radar (SAR)
Stanley F. Radford
Dynamics Technology, INC.
21311 Hawthorne Boulevard
Torrance, California 90503

Application of Defense Technologies to the Fisheries (Long Range Broadband Sonar/Neural Net Signal Processing
Scientific Fishery Systems Inc.
Patrick K. Simpson
17436 Ashburton Road
San Diego, CA 92128
Phone: (619) 675-0962

An experimental "Pair-Trawling" fishing trip for yellowfin tuna in the eastern tropical Pacific Ocean
Teresa Platt
826 Orange Avenue, #504
Coronado, CA 92118
Phone: (619) 575-4664
FAX: (619) 575-5578

Acoustic Dolphin-Tuna Separator
Axiom Technology International Corporation
Mr. Mark Hladky
1893 W. New Haven Avenue, #157
Melbourne, FL 32904
Phone: (800) 284-9880

Fish Detection and Discrimination
IsComp Systems, Inc.
Dr. Jesse (Jim) Butts
5777 West Century Blvd., Suite 560
Los Angeles, CA 90045
Phone: (310) 641-3260

Acquisition and Identification of Sub-Aural Acoustic Signals from Schools of Tuna
Seaway Technologies, Inc.
Mr. Jim Ash
5547 Main Street
New Port Richey, FL 34652
Phone: (813) 846-7733

Automated Airborne Tuna School Detector
Arete' Associates
Dr. Philip J. Davis
P.O. Box 6024
Sherman Oaks, CA 91413
Phone: (818) 501-2880

Long-Range Tuna Detection and Identification
Scientific Fishery Systems, Inc.
Mr. Patrick K. Simpson
17436 Ashburton Road
San Diego, CA 92128
Phone: (619) 675-0962

Skyhook - Airborne biomass estimation of fish stocks
Gulf Aviation Corp.
5717 Prince Lane
New Orleans, Louisiana 70126
Contact: William G. Rheams (Chairman of the Board)
(504) 242-4364

Airborne Video system for natural resource data collection Pentec Environmental, Inc.
120 West Dayton, Suite A7
Edmonds, Washington 98020
Contact: Michael Meagher (PI- Software Engineer)
(206) 775-4682

Remote sensing for fish biomass estimation
Ciencia, Inc.
111 Roberts St. Suite C,
East Hartford, CT 06108
Contact: Salvador M. Fernandez (President)
(203) 528-9737

An analysis of the application of visible-band hyper-spectrometry in the airborne biomass estimation of pelagic fish stocks
Kestrel Corporation
6020 Academy Blvd. N.E. , Suite 104
Albuquerque, New Mexico 87109
Contact: L. John Otten III Ph. D.
(505) 823-9844

Multi-spectral imaging sensor
Pacific-Sierra Research Corporation
2901 28th St. 3rd Floor
Santa Monica, CA 90405
Contact: Richard F. Lutomirski
(310) 314-2382

Dolphin-Safe Purse-Seining using Dual-Bioacoustic Separation
Science Applications International Corporation (SAIC)
3990 Old Town Avenue
Suite 205C
San Diego, CA
Contact: Clancy Hatleberg Ph. D.
(619) 686-5635

Airborne Imaging Lidar for Biomass Estimation: Analysis of existing Imaging Lidar images and development of automatic detection and recognition algorithms

Arete' Associates
Andrew J. Griffis
PO Box 32348
Tucson, AZ 85751-2348
(602) 571-8660

Image Processing for Biomass Estimation of Fish Stocks: Stereo-Image Recorders and Image Processing Software

ENSCO, INC.
Dr. Geof Creede
5400 Port Royal Road
Springfield, VA 22151
(703) 321-9000

Active Airborne Sensor for Fish Stock Biomass Estimation: Blue-Green Laser Sensor

CW Optics, INC.
L. W. Winchester, Jr.
117 Quantico Loop
Yorktown, VA 23693-2611
(804) 867-7893

Airborne High Speed Shuttered Digital Telescopic Video Camera System with Synchronized Laser Illumination for Biomass Estimation of Fish Stocks

SHARPENIT
Paul Zagarino
7164 Del Norte Dr.
Goleta, CA 93117
(805) 968-4591

Airborne Biomass Estimation of Fish Stocks: Active and Passive Acoustic Signal Processing

ORINCON Corporation
Dr. Larry L. Burton
9363 Towne Centre Drive
San Diego, CA 92121-3016
(703) 351-4440 Ext. 104

Sensor Development for Airborne Biomass Estimation of Fish Stocks: Pulsed-gated laser

DCS CORPORATION
Richard T. Flaherty
1330 Braddock Place
Alexandria, VA 22314

(703) 683-8430 Ext. 290

Multispectral Fish Assessment System: Intensified Multispectral Video (six bands) in the visible and infrared regions with automatic detection software

Xybion Corporation
Terren Niedrauer
240 Cedar Knolls Road
Cedar Knolls, NJ 07927
(201) 538-5111

Study the use of Sonobuoys for Biomass Estimates: Evaluation of "off-the-shelf" military airborne hardware deploying a combination of low-frequency passive and high-frequency active acoustic signals

Marine Acoustics, INC.
Lee Shores
2345 Crystal Drive, Suite 901
Arlington, VA 22202
(703) 418-1866

Multi-Sprectral Airborne Stock Search (MASS): Real-time 3-CCD chip video imaging techniques developed for the Hubble Space Telescope

Arizona Research Institute (TM)
Devon G. Crowe
4663 East Chaco Place
Tucson, AZ 85718
(602) 529-5839

Automated Airborne Tuna School Detector: Phase 2 effort to build and test multispectral video imaging system with automatic recognition

Arete' Associates
Philip J. Davis
P.O. Box 6024
Sherman Oaks, CA 91413
(818) 501-2880

Three-dimensional airborne Lidar for bycatch reduction

Arete' Associates
Andrew J. Griffis
PO Box 32348
Tucson, AZ 85751-2348
(602) 571-8660

Airborne Lidar for the detection and classification of marine life

SatCon Technology Corporation
Frank T. P. Cianciotto
161 First Street
Cambridge, MA 02142-1221
(617) 349-0817

Long-range tuna school detection sonar
Scientific Fishery Systems, INC.
Patrick K. Simpson
P.O. Box 242065
Anchorage, AK 99524
(907) 345-7347

Airborne multispectral tuna detection system
Xybion Corporation
Terren Niedrauer
240 Cedar Knolls Road
Cedar Knolls, NJ 07927-1698
(201) 538-5111

Facilitating capture of tuna in the purse seine fishery using acoustic signals to debilitate tuna
Nature's Own Research Association
James L. Oschman
P.O. Box 5101
Dover, NH 03821-5101
(603) 742-3789